

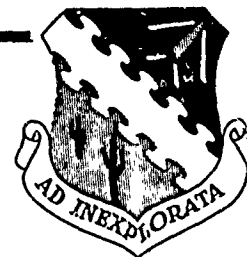
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**LIMITED HIGH ALTITUDE
PERFORMANCE EVALUATION
OF THE
HH-53C HELICOPTER**

RODNEY L. RITTER
Captain, USAF
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TECHNICAL REPORT No. 71-54

DECEMBER 1971

Distribution limited to U.S. Government agencies only
(Test and Evaluation), November 1971. Other requests
for this document must be referred to ASD (SDQM),
Wright-Patterson AFB, Ohio 45433.

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WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433



REPLY TO
ATTN OF

ASD/SDQH 5-27 (Maj Thompson/54921/cal/H-53/R&D 9-2)

SUBJECT

ASD Addendum to FTC-TR-71-54, H-53 Altitude Performance

10 Recipients of FTC-TR-71-54

This report is a part of and should remain attached to FTC-TR-71-54, "Limited High Altitude Performance Evaluation of the H-53C Helicopter". Paragraph numbers below correspond to the recommendations in the AFFTC Technical Report.

1. Concur. ASD will accomplish the data analysis required to incorporate this test data in the flight manual (along with data from previous tests, which is being reduced by commercial contract). All available flight test data will be incorporated simultaneously.

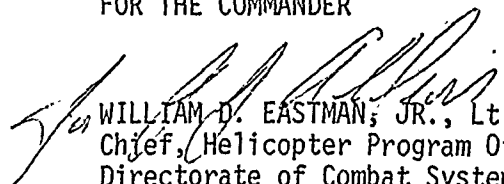
2. Concur with intent. ASD has initiated actions to incorporate the required information in the flight manual.

3. Concur. Test data analysis indicates that the largest increase in hover weight capability (at 9500 feet, standard day, and 100% N_r) due to the new bellcrank alone is approximately 2650 pounds. ASD provided technical approval of the Engineering Change Proposal (ECP 7379) with the recommendation that WRAMA procure the bellcrank for the H-53 fleet.

4. Concur. The ASD data effort for the flight manual will consider this compromise of optimum performance in favor of safety.

5. Concur with intent. ASD has established an additional data analysis task to determine the feasibility of defining single engine performance without further flight tests of H-53 helicopters. This effort is undertaken to determine the extent of additional test data which may or may not be required to further define the single engine height-velocity characteristics, if deemed necessary at a later date.

FOR THE COMMANDER


WILLIAM D. EASTMAN, JR., Lt Col, USAF
Chief, Helicopter Program Office
Directorate of Combat Systems
Deputy for Systems

PRIDE IN THE PAST



FAITH IN THE FUTURE

FTC-TR-71-54

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FOREWORD

This report presents the results of the limited high altitude performance tests and tail rotor evaluation of an HH-53C helicopter, USAF serial number 68-10354. Testing was conducted between 26 September and 16 November 1971 at Bishop, California, and the nearby high altitude test site, Coyote Flats. The tests were conducted under authority of AFFTC Project Directive 72-17.

The authors of this report wish to express their appreciation to Airman Gary Snitily for his assistance with the data reduction and engineering analysis. In addition, the dedicated efforts of SMSgt Frank M. Presbury and his maintenance crew are most thankfully acknowledged.

Foreign announcement and dissemination by the Defense Documentation Center are not authorized because of technology restrictions of the U.S. Export Control Acts as implemented by AFR 400-10.

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ABSTRACT

This limited flight test program defined the hover and takeoff performance of the HH-53C helicopter at high altitude and included an evaluation of the increased tail rotor power provided by a new tail rotor bellcrank. Hover and takeoff performance were satisfactory during high altitude testing. Operating at 105-percent rotor speed at high altitude, heavy gross weight combinations provided a more rapid response of the aircraft to control inputs than operation at 100-percent where control response was somewhat sluggish. In addition, it provided increased performance, prevented reaching mechanical control stops from limiting performance and lowered cruise guide readings. The new tail rotor bellcrank increased the HH-53C lift capability approximately 4,500 pounds by preventing tail rotor authority from limiting aircraft performance. A compromise between maximum performance and safety resulted in recommendation of a 35 knot indicated airspeed for takeoff.

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list of abbreviations and symbols

<u>Item</u>	<u>Definition</u>	<u>Unit</u>
A	rotor disk area	ft ²
AFCS	automatic flight control system	- - -
avg	average	- - -
C	centigrade or Celsius	- - -
C _p	pressure coefficient	dimensionless
C _T	thrust coefficient	dimensionless
cg	center of gravity	in.
dh/dt	time rate of change of altitude	ft per min
FAT	free air temperature	deg C
fwd	forward	- - -
IGE	in ground effect	- - -
KIAS	knots indicated airspeed corrected for instrument error	- - -
N _r	rotor speed	rpm
Q	engine torque	pct
R	rotor radius	ft
R/C	rate of climb	ft per min
rpm	revolutions per minute	- - -
SHP	shaft horsepower	550 $\frac{\text{ft-lb}}{\text{sec}}$
T _a	ambient temperature	deg K
W	airplane gross weight	lb
ρ	air density	slugs per ft ³
Ω	rotor angular velocity	rad per sec



INTRODUCTION

Previous HH-53C hover performance testing as reported in references 1 and 3 was accomplished only at sea level. As a result of the earlier tests, it was recommended that high altitude testing be accomplished to adequately define the operational envelope of the aircraft (reference 1). In addition, the HH-53C has experienced growth in its performance capabilities. Engine power has increased from an original 3,435 shaft horsepower (SHP) to the present value of 3,925 SHP, the main gearbox's torque capability has increase 18 percent, and for the tests reported herein, T_5 limits were raised from 727 to 750 degrees C. These increased performance capabilities resulted in a tail rotor control problem as was reported in reference 4. Reports from operational users noted that the tail rotor does not have sufficient control power to overcome the torque generated by the main rotor at high altitude and heavy gross weight combinations. To prevent lack of tail rotor control from limiting the performance of the HH-53C a new tail rotor bellcrank was installed on the test aircraft which increased the available tail rotor blade angle by 3.25 degrees. Effects of the new tail rotor bellcrank were evaluated during these high altitude tests. Also, limited takeoff performance, sawtooth climbs, and a qualitative approach evaluation were accomplished on an opportunity basis.

All tests were conducted with engine air particle separators (EAPS), 450-gallon tip tanks and rescue hoist installed. Thirty-two flights for a total of 55.4 hours were flown to acquire the data presented within this report.

TEST AND EVALUATION

PERFORMANCE

Hover

Hovering performance was evaluated, using tethered hover techniques, at wheel heights of 150, 100, 80, 47, 22, and 10 feet. Two locations, Bishop Airport (4,100 feet) and nearby Coyote Flats (10,000 feet), were used so that a sufficient temperature range was available to test four different rotor blade tip Mach number (M_{tip}) values (0.60, 0.62, 0.64 and 0.66). The data are presented in nondimensional form, thrust coefficient (C_T) versus pressure coefficient (C_p) for lines of constant M_{tip} (figures 1 to 6, appendix), and wheel height versus C_p for lines of constant C_T (figures 7 to 10, appendix). Plots present previous acquired data (reference 3) as well as the results of the test program reported herein. These data should be used to update the HH-53C Flight Manual (reference 2). (R 1)

Takeoffs

Takeoff data were obtained by using a level acceleration takeoff technique at wheel heights of 5 and 15 feet. The 15-foot wheel height was used to simulate the carrying of an external sling load. All flights were made with a mid cg and with the landing gear down. The distance required to clear a 50-foot height was obtained through a range of ΔC_p 's for the two techniques by varying the gross weight of the aircraft from 36,500 to 40,500 pounds. A Fairchild Flight Analyzer was used to record time, height and distance of each takeoff. Figures 11 through 20 of the appendix present these data.

The helicopter was hovered at the two wheel heights using 105-percent rotor rpm, and the power required to hover was noted. The helicopter was then accelerated at the hover height as rapidly as possible to an aim airspeed by pulling the collective to maximum power available or until the rotor rpm dropped to 100 percent. When the helicopter reached the desired indicated airspeed in a level acceleration, the airspeed was maintained in a climb until the helicopter or the simulated sling load cleared the desired 50 foot altitude above the ground. The power required at this point was noted. The difference between the power required in hover and at 50 feet was the ΔC_p against which takeoff distance was plotted in the previously mentioned figures. For purposes of the test a pace vehicle was used during the acceleration and climb at speeds below 35 knots. Figures 15 and 20 show that the minimum takeoff distance occurs when accelerating to 25 knots and climbing out, while maintaining this speed. This airspeed is not recommended because of inherent inaccuracies in the airspeed indicator at low airspeeds and the large attitude changes required in rotating from a nose low attitude for level acceleration to a nose high attitude for a low speed climb. For an opera-

¹ Boldface numerals preceded by an R correspond to the recommendation numbers tabulated in the Conclusions and Recommendations section of this report.

tional takeoff situation it is necessary to compromise between maximum performance and safety. If a climbout is attempted at 25 knots, a slight over-rotation or a minor attitude change during the climb can cause the airspeed to drop off to such a point that the aircraft can no longer climb and will settle back to the ground. From pilot experience during the takeoff tests, 35 KIAS was the lowest indicated airspeed that was stable enough to be utilized during the takeoff climb.

The acceleration close to the ground and climbout at 35 KIAS provided for a much safer operation. The climb airspeed was very close to the minimum single engine speed of approximately 40 KIAS. A maximum performance takeoff must necessarily be accomplished within the avoid area of the height-velocity diagram; however, single engine speed could possibly be attained if the climbout was at 35 KIAS or a much more controlled touchdown could be made if necessary. For these reasons it is recommended that level acceleration takeoff data be presented using 35 KIAS for the climb. (R 4)

Height-velocity tests have never been conducted at weights greater than 37,000 pounds or at high altitude. A qualitative evaluation of minimum single engine airspeed was made and found to be approximately the same (40 KIAS) as at lower elevation. Single engine out performance should be defined at high altitudes. (R 5)

Sawtooth Climbs

Sawtooth climbs were made with 100- and 105-percent rotor speeds at approximately 41,000 pounds gross weight. At a density altitude of approximately 11,300 feet collective limits reduced the rate of climb while operating at 100-percent rotor speed as compared to the rate of climb at 105 percent. Figure 21 presents this data. It is recommended that a rotor speed of 105 percent be used when operating at high altitudes and heavy gross weight combinations. (R 2)

Approaches

High altitude approaches were not specifically evaluated during the performance tests, but enough general observations were made during normal day-to-day operations at the test site to form qualitative opinions concerning the best technique to use when making approaches into a high altitude site at high gross weights. Numerous approaches were made to the high altitude site at 42,000 pounds gross weight and with power margins as low as 10-percent torque (20-percent torque total). Approaches were made to both running landings and a low hover. Approaches were made at a higher true airspeed (same indicated airspeed) than at lower altitudes and caused increased difficulty in slowing the helicopter during the approach, particularly to a hover. Approaches to a running landing are recommended when a suitable landing area is available and excess hover power is marginal. Running landings with touchdown speeds in the normal 20 to 40 knot range resulted in noticeably higher ground speeds than experienced at lower elevations. This must be anticipated because of the inadequacy of the HH-53C wheel brakes. If a running landing is made and the brakes must be used to stop the helicopter, very short brake life can be expected, especially if minimum distance stops are made with the helicopter at high gross weight. The helicopter can be effectively slowed to a stop by proper application of collective and cyclic controls.

Approaches to a hover were made using a slow, shallow approach to prevent buildup of excessive descent rates or a requirement for a flare to slow the helicopter during the last portion of the approach. There was a tendency for the helicopter to "fall through" as translational lift was lost. This momentary loss of lift was anticipated by insuring that near hover power was applied as the helicopter passed through translational lift, thus reducing the requirement for a sudden application of collective and possible rotor (N_r) droop. A rotor speed of 105 percent was used on all heavy weight, high altitude approaches to allow a margin above 100-percent N_r in case the rotor speed was inadvertently drooped when increasing the collective to maximum power. It is recommended that all high altitude, heavy weight approaches be made using maximum rotor speed (full throttles/105-percent) to allow use of maximum power and to avoid reaching an aircraft mechanical limit (tail rotor or collective). (R 2)

DIRECTIONAL CONTROL EVALUATION

As previously stated the test helicopter was equipped with a new tail rotor bellcrank which increased the control travel of the tail rotor blades by approximately 10 percent. Originally, the tail rotor blade travel was from -3.5 degrees (full right rudder pedal, full down collective) to +24 degrees (full left rudder pedal, full up collective). The new bellcrank maintained the full right pedal, down collective tail rotor blade angle of -3.5 degrees, but increased the full left pedal, up collective blade angle to +27.25 degrees.

Two different methods were used to evaluate the effectiveness of the new tail rotor bellcrank: (1) Pacing of an in-ground-effect (IGE) flight, from left sideward through rearward to right sideward flight, and (2) tethered hover in winds of various velocities.

Sideward and Rearward Flight

Sideward and rearward flights were conducted at a mid cg (340 inches) 39,000 pounds gross weight and forward cg (328 inches) at 37,500 pounds gross weight. Rotor speeds were 102 and 100 percent, respectively. In addition, left and right sideward flight at 97-percent rotor speed, mid cg (340 inches) and 39,000 pounds gross weight were conducted to compare rotor speed effects. Figures 22 through 28 present these data.

The discontinuities present in the data fairings represent the speed (approximately 20 knots) at which translational lift becomes evident. Comparing sideward flight performance at 102 and 97 percent rotor speed, it is evident that variations in rotor speed significantly influence the aircraft's capabilities. The conventional bellcrank blade angle limits are included in the plots. It can be seen that the new bellcrank significantly increased the sideward flight capability. Where two data points are presented they represent the absolute maximum and minimum values recorded during that particular data point. At 97-percent rotor speed the aircraft is collective limited in left sideward flight and tail rotor blade limited in right sideward flight. The lower rotor speeds increased cruise guide readings, as was expected (reference 2). Higher rotor speeds (above 100-percent, see section Tethered Hover) resulted in more normal response higher directional control capability, and reduced cruise guide readings. When operating the HH-53C at high altitudes, 105-percent rotor speeds should be used. (R 2)

Tethered Hover

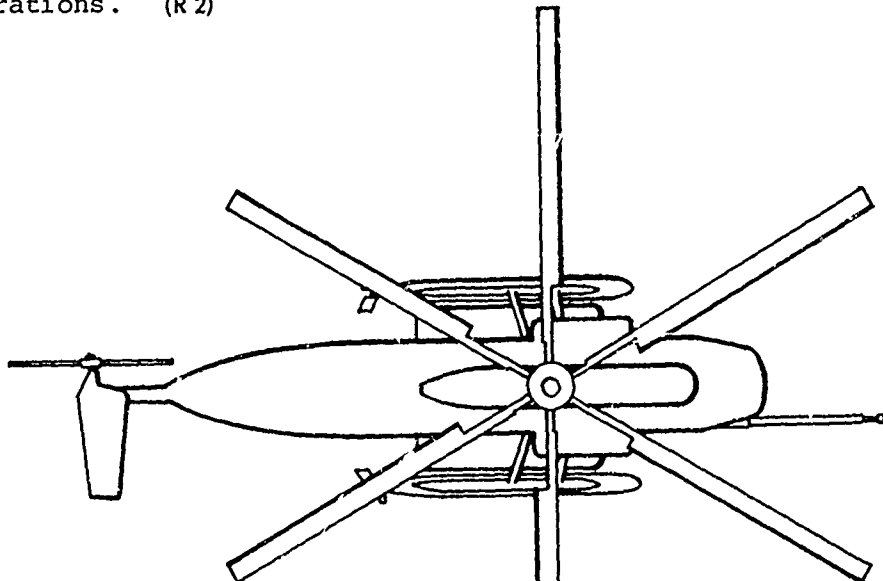
Hover data were obtained using tethered hover techniques. Increasing gross weights up to the limit gross weight were simulated by pulling on a cable tethered to the ground. Power was increased until reaching the gross weight limit or an aircraft power or control limit.

Hover testing was performed at Coyote Flats and Bishop Airport.

While hovering in a wind, various aircraft headings relative to the wind could easily be established. Then, by monitoring tail rotor torque and blade angle, a critical relative heading was determined. At approximately 200 degrees relative heading the HH-53C experienced a shuddering, similar to that felt when translational lift is lost during approach to a hover. However, maximum blade angle and tail rotor torque were obtained at approximately 80 degrees relative heading.

Tethered hover in little or no wind (3 knots or less) showed the new tail rotor bellcrank to be sufficient for C_T values up to 107 (figures 30 through 33). At 9,500 feet pressure altitude, the new bellcrank increased the HH-53C's capability by approximately 4,500 pounds. The new bellcrank will prevent any tail rotor control problems for the present aircraft limits. It should be utilized to prevent lack of tail rotor control from limiting aircraft performance. (R 3)

During all tethered hover tests, the helicopter's handling and control response were satisfactory. To obtain referred performance data, rotor speed ranged from 95 to 105 percent. No control response problem was encountered even at the relatively low rotor speed of 94 percent. However, at rotor speeds below 100 percent, control response was sluggish and consequently more fatiguing to the pilot when trying to maintain a stable hover. When operating at rotor speeds below 100 percent, collective and tail rotor mechanical limits were occasionally reached. To maintain a more normal control response and insure full utilization of available engine power without being limited by a mechanical control stop a rotor speed of 105 percent should be used for high altitude, heavy gross weight hover operations. (R 2)



CONCLUSIONS AND RECOMMENDATIONS

The HH-53C helicopter's hover and takeoff performance were satisfactory during high altitude testing. Operating at 105-percent rotor speed at high altitude, heavy gross weight combinations provided a more rapid response of the aircraft to control inputs than operation at 100 percent where control response was somewhat sluggish. In addition, it provided increased performance (more power available), avoided reaching mechanical control stops (collective or tail rotor) which would limit performance, and lowered cruise guide readings. The new tail rotor bellcrank increased the HH-53C lift capability approximately 4,500 pounds by preventing lack of tail rotor authority from limiting aircraft performance.

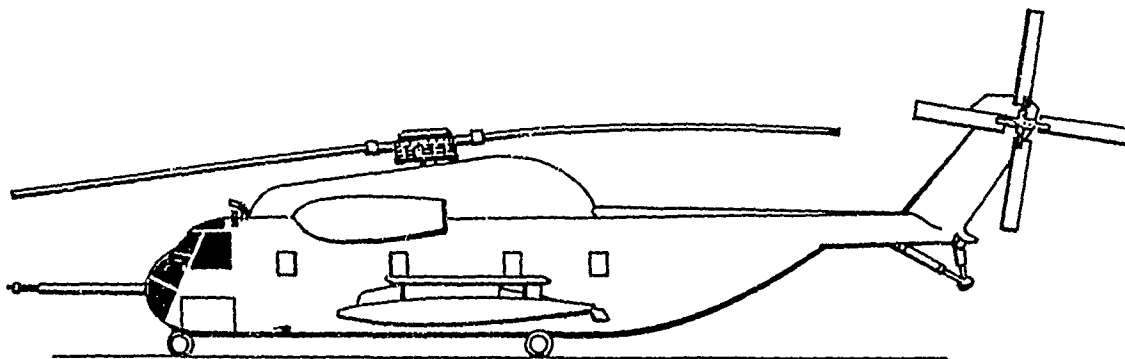
1. The hover data presented in this report should be used to update the HH-53C Flight Manual (page 2).
2. A rotor speed of 105 percent should be used for high altitude, heavy gross weight combinations (pages 3, 4, and 5).
3. The new tail rotor bellcrank should be incorporated to prevent the lack of tail rotor control from limiting the aircraft's performance (page 5).

Maximum takeoff performance over a 50-foot obstacle was obtained by climbing at approximately 25 knots. However, a compromise between performance and safety dictated the use of 35 knots.

4. Takeoff charts should be based on 35-knot climbout speeds (page 3).

Height velocity tests have never been conducted at weights greater than 37,000 pounds gross weight or at high altitude.

5. Single engine out performance should be defined at high altitudes (page 3).



APPENDIX I

DATA ANALYSIS METHODS AND TEST DATA

GENERAL

Dimensional analysis of the major items affecting helicopter performance yields several sets of dimensionless variables which can be used to present performance data in a useful nondimensional form. These variables are defined as follows:

$$C_p = \frac{\text{SHP} \times 550}{\rho A (\Omega R)^3}$$

$$C_T = \frac{W}{\rho A (\Omega R)^2}$$

$$M_{\text{TIP}} = \frac{\Omega R}{38.967 \sqrt{T_a}}$$

Where SHP is in foot-pound x 550 per second, ρ is the air density in slugs per foot cubed, A is the rotor disc area in feet squared, Ω is the rotor angular velocity in radians per second, R is the rotor radius in feet, and T_a is the temperature of the ambient air in degrees Kelvin.

POWER DETERMINATION

The HH-53C employed an electronic torque monitoring system to measure the percent of torque being applied by each engine to the main transmission. A torque reading of 100 percent was equivalent to 3,200 SHP. The torque sensing system was located at the engine input section to the nose gearbox and was made up of the torque shaft, torque pickup, the phase detector, and the torque indicator. The torque sensor shaft consisted of an inner and outer shaft arranged so that the inner shaft was subjected to the power turbine load. The major diameter on each shaft was machined to contain 72 teeth. This portion of the shaft was the exciter. The torque pickup was a coil installed in the torque tube opposite the exciter.

The system measured torque by measuring the twist in the shaft connecting the engine to the load. To measure this twist a pickup was installed in the torque tube opposite a pair of gear teeth on the rotating shaft. As the shaft rotated, two ac signals were induced in the pickup coils. As the torque in the shaft increased, the two sets of teeth were displaced from each other as the shaft twisted and the phase angle difference between the two ac voltages changed. The output of the pickup coils was fed into a phase detector that electronically measured the phase angle change. This phase angle was then converted to an output

voltage proportional to torque. Test SHP was determined from inflight torquemeter readings and rotor rpm using the following equation.

$$\frac{\text{SHP}}{\text{engine}} = \frac{(13,600) (\% \text{ rpm}) (\% Q) (1,235)}{5,250}$$

Where Q is percent torque reading from the aircraft's instruments.

SAWTOOTH CLIMBS

The data presented in figure 21 of this appendix are the test day observed rates of climb corrected to tape line rates of climb using the following equation:

$$R/C_t = \frac{dh}{dt} \times \frac{T_{a_t}}{T_{a_s}}$$

where R/C_t was the tapeline rate of climb in feet per minute, dh/dt being the slope of the pressure altitude versus time curve in feet per minute. T_{a_t}/T_{a_s} was the ratio of the test day ambient temperatures to the standard day temperature for the test altitude.

CONTROL POSITIONS

The following controls and their positions were monitored during the tail rotor evaluation portion of these tests: lateral and longitudinal cyclic stick, collective stick, and rudder pedals. Sensors were located in the "broom closet" located on the aft side of the bulkhead dividing the cockpit and cargo area. These pickups only registered control inputs. The actual control output was a function of the pilot input, collective-rudder pedal coupling, and the automatic flight control system (AFCS). Consequently, the following additional parameters were also monitored: the AFCS servo output, tail rotor blade pitch angle and the tail rotor torque.

The AFCS's input occurs in series with pilot's input and does not necessarily show as a control position change. It is possible for the pilot to have 20-percent left rudder pedal travel remaining, yet have the tail rotor blade angle at the limit (+27.25 degrees). This phenomenon occurs in the data presented in the tail rotor evaluation. It is a result of the collective-rudder coupling and AFCS authority. Figure 34 shows how collective position can affect rudder pedal position and tail rotor blade angle.

Arbitrarily, 100-percent right rudder pedal was defined as that position where collective was full down and tail rotor blade angle was -3.5 degrees with AFCS off. Left rudder (0 percent) was defined at full up collective with tail rotor blade angle at +27.25 degrees.

Figure 35 shows this situation: full right rudder is applied (full pedal travel; collective control is full down; now, when the collective control is raised, the rudder pedal travel available increases, although the tail rotor blade angle actually decreases. Figure 36 shows the converse of this (up collective, left pedal).

FH-53G USAF S/N 68-10554

T64-GE-7 ENGINES

10 FOOT WHEEL HEIGHT

450 GALLON FUELTANKS INSTALLED

- NOTE: 1. ALL DATA WITHOUT EAPS
OBTAINED FROM EARLIER TESTS REF F3 ETC-TR-70-8
2. SHADED SYMBOLS DENOTE
FREE FLIGHT HOVER
3. TAILED SYMBOLS DENOTE
HIGH ALTITUDE HOVER WITH
EAPS INSTALLED

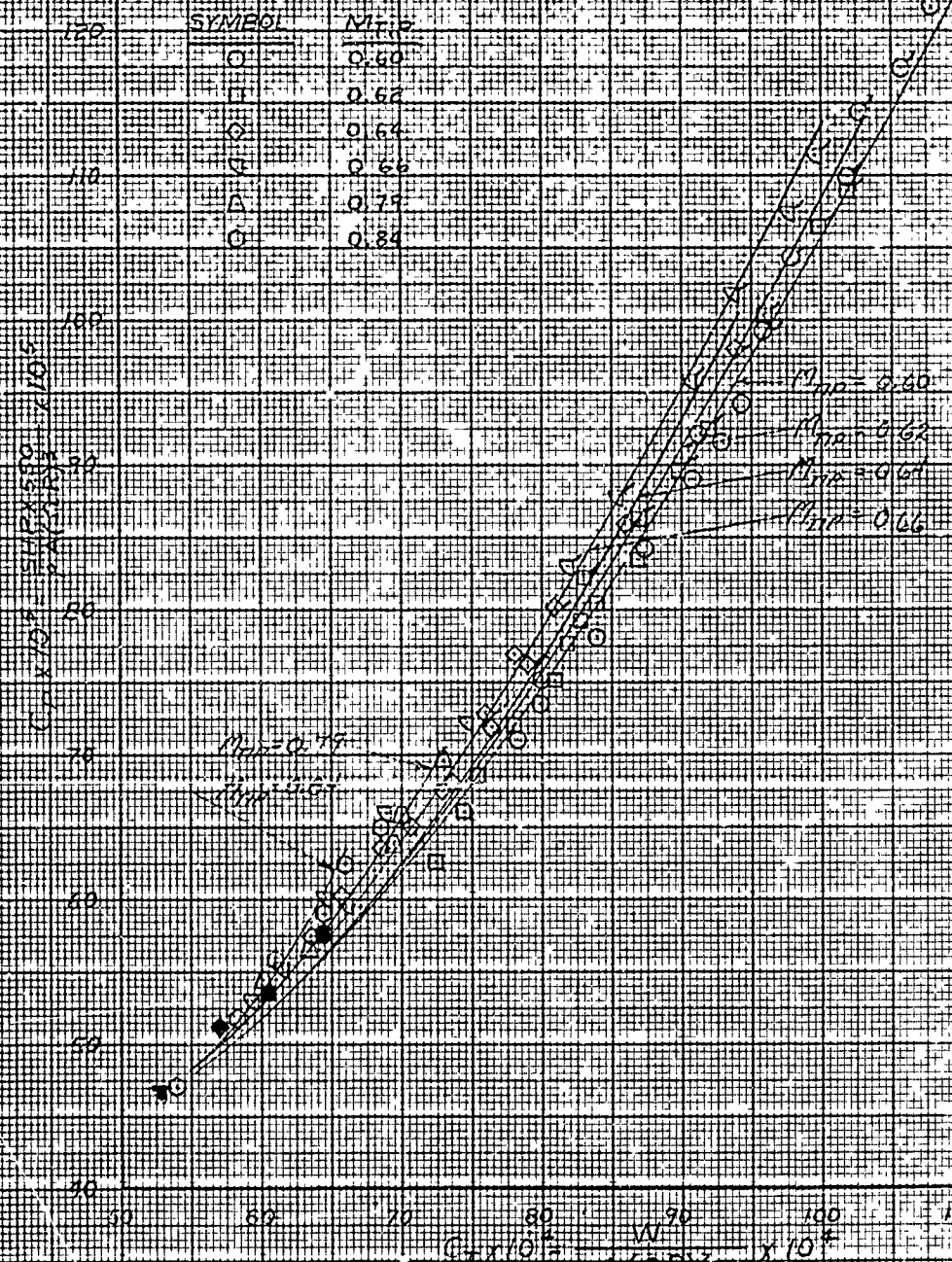


Figure 1

Nondimensional Hovering Performance

HH-53C USAF S/N 68-10354

T64-GE-7 ENGINES

22-FOOT WHEEL HEIGHT

450 GALLON TIPTANKS INSTALLED

NOTE: 1. ALL DATA WITHOUT EAPS

OBTAINED FROM EARLIER TESTS REF 1, 3, ETC. TR-70-8

2. SHADED SYMBOLS DENOTE

FREE FLIGHT HOVER

3. TAILED SYMBOLS DENOTE

HIGH ALTITUDE HOVER WITH

EAPS INSTALLED

SYMBOL MHP

○ 0.60

□ 0.62

○ 0.64

□ 0.66

○ 0.79

○ 0.80

100
90
80
70
60
50
40
30
20
10
0

40
50
60
70
80
90
100
110
120

$\times 10^4$

$\times 10^4$

PAC(R)

Figure 2

Non-dimensional Hovering Performance

10

HH 53C USAF SIN 68-10354

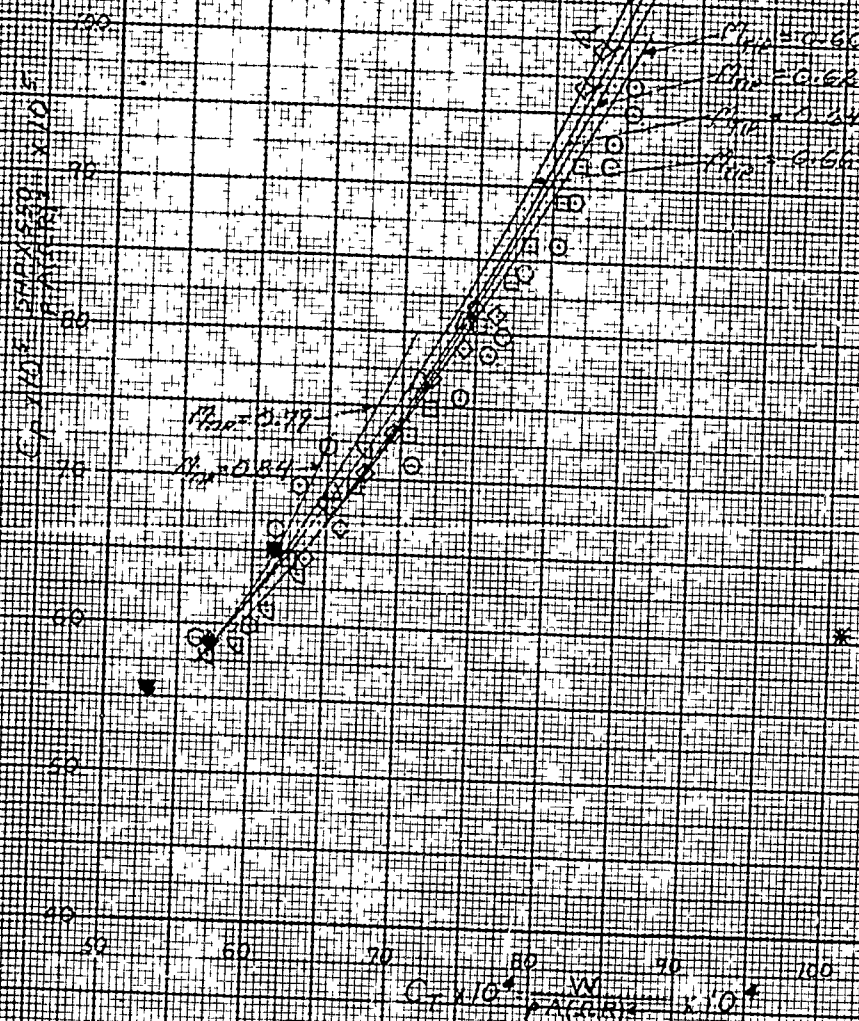
T64-GE-7 ENGINES

47 FOOT WHEEL HEIGHT

450 GALLON TILTANKS INSTALLED

NOTE: 1. ALL DATA WITHOUT FAPE
OBTAINED FROM EARLIER TESTS *
2. SHADED SYMBOLS DENOTE
FREE FLIGHT HOVER
3. TAILED SYMBOLS DENOTE
HIGH ALTITUDE HOVER WITH
FAPE INSTALLED

SYMBOL	MTIP
○	0.60
◐	0.62
◑	0.64
◒	0.66
◓	0.79
◔	0.84



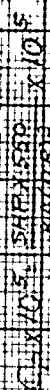
* REF L 3
FIG-TR-70-B

Figure 8. Dimensional Hovering Performance

450 GALLON TITANKS INSTALLED

140 NOTE: 1. ALL DATA WITHOUT EAPS
OBTAINED FROM EARLIER TESTS. 2
2. SHADED SYMBOLS DENOTE
FREE FLIGHT HOVER.
150 3. TAILOD SYMBOLS DENOTE
HIGH ALTITUDE HOVER WITH
EAPS INSTALLED.

SPM501	Math
O	0.60
P	0.62
Q	0.64
R	0.66
S	0.79
T	0.82



$\sigma_{yy} = 0.60$
 $\sigma_{zz} = 0.58$
 $\sigma_{xx} = 0.64$
 $\sigma_{xy} = 0.66$

* REF 1,3
ETC-TR-70-8

C-110⁴ W-110⁴

Figure 4 Nondimensional Hovering Performance

HH-53C USAF SYN 68-10354

764-GE-2 ENGINES

100-FOOT WHEEL HEIGHT

450-FOOT WHEEL HEIGHT

NOTE: ALL DATA WITHOUT EAPS OBTAINED

FROM EARLIER TEST REF 1, 3 & 4

SHADED SYMBOLS DENOTE

FREE FLIGHT HOVER

3-TAILED SYMBOLS DENOTE

HIGH ALTITUDE HOVER WITH

EAPS INSTALLED

SYMBOL	NOTE
○	0.54
○	0.56

$M_{TWR} = 0.64$

$M_{TWR} = 0.66$

SYMBOLS
UNSHADED
3-TAILED

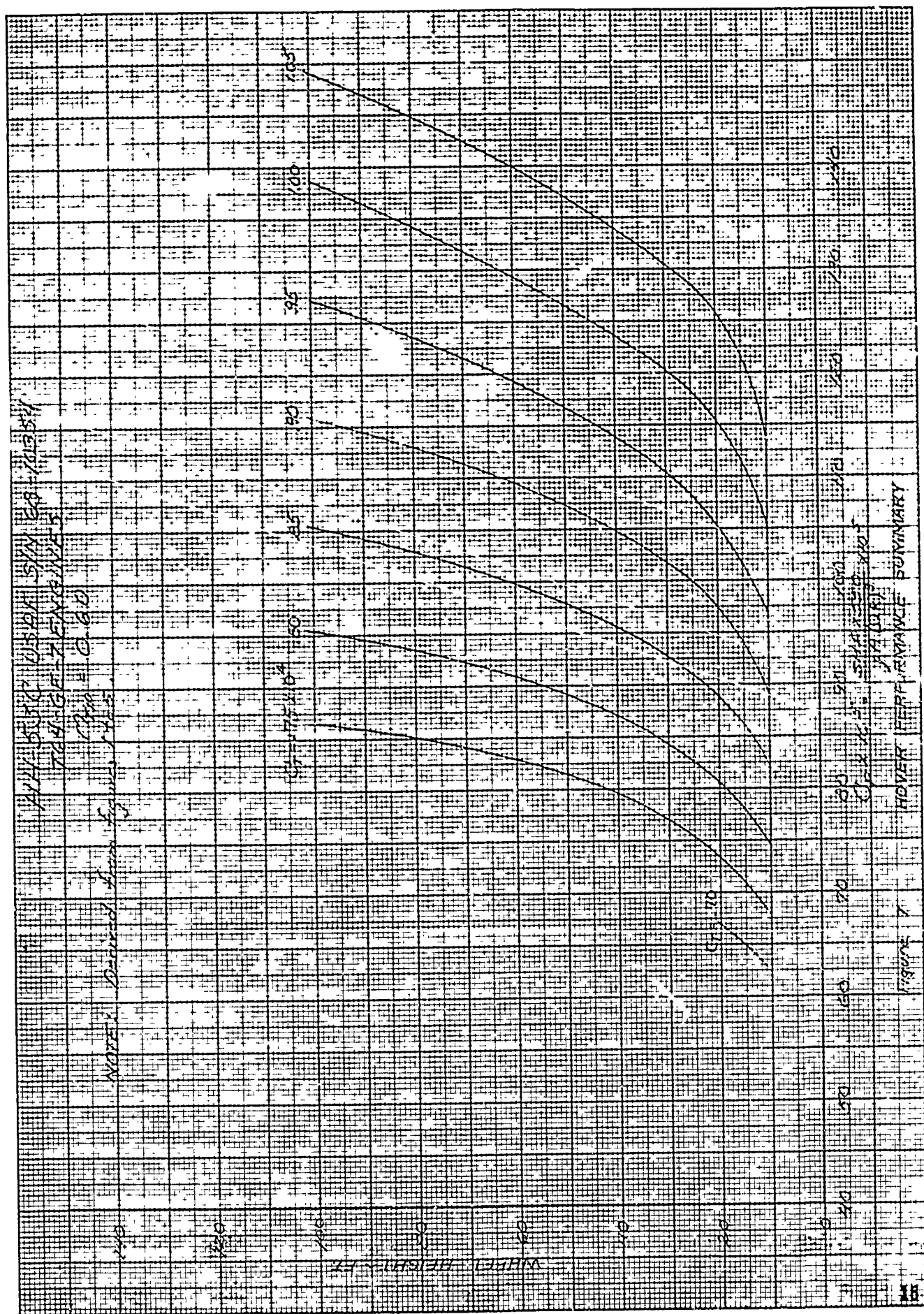
* FIG-TR 10-B

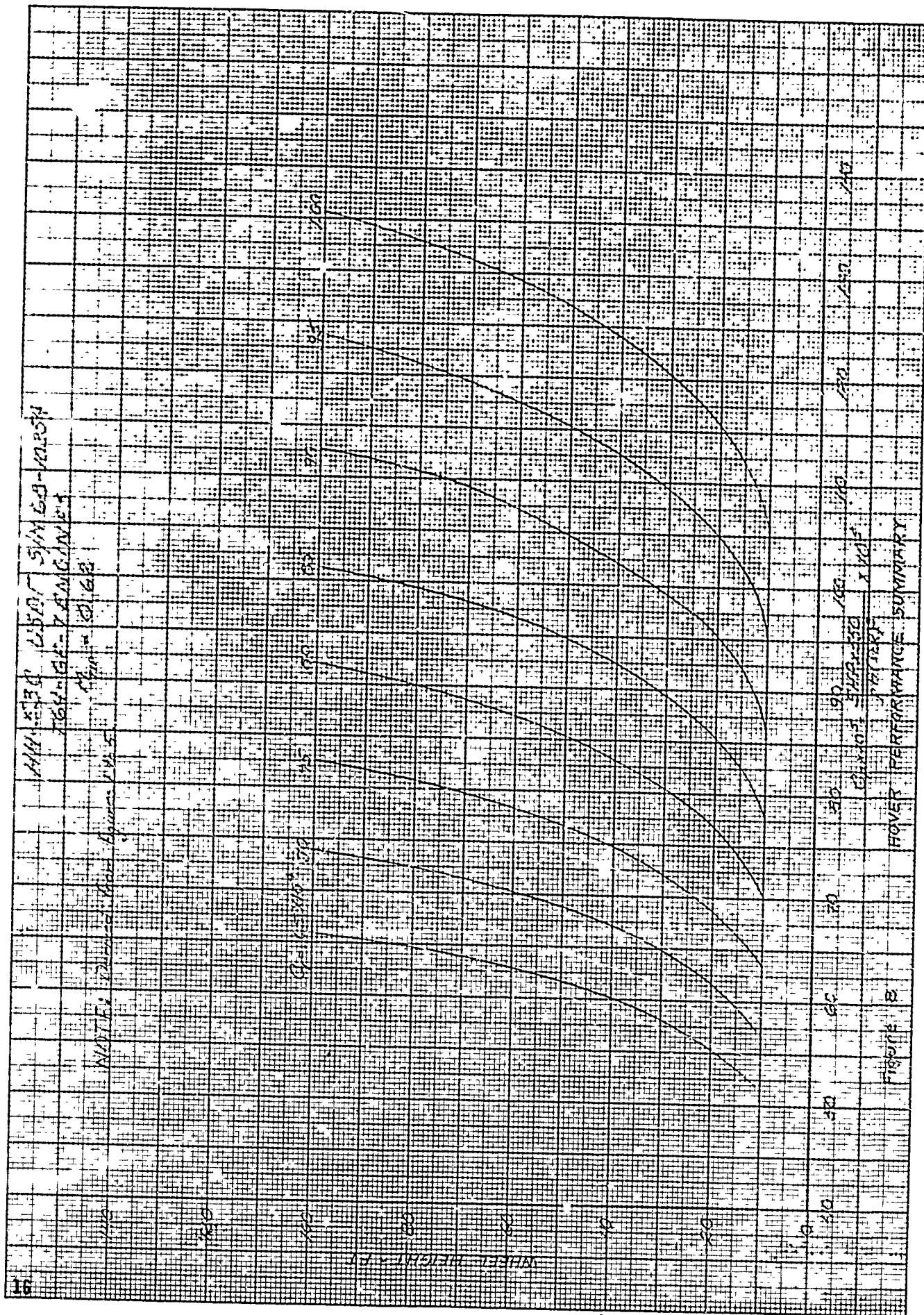
30 40 50 60 70 80 90 100 110 120

$C_{X10K} \times 10^4$

REMARKS

Figure 6 Nondimensional Hovering Performance

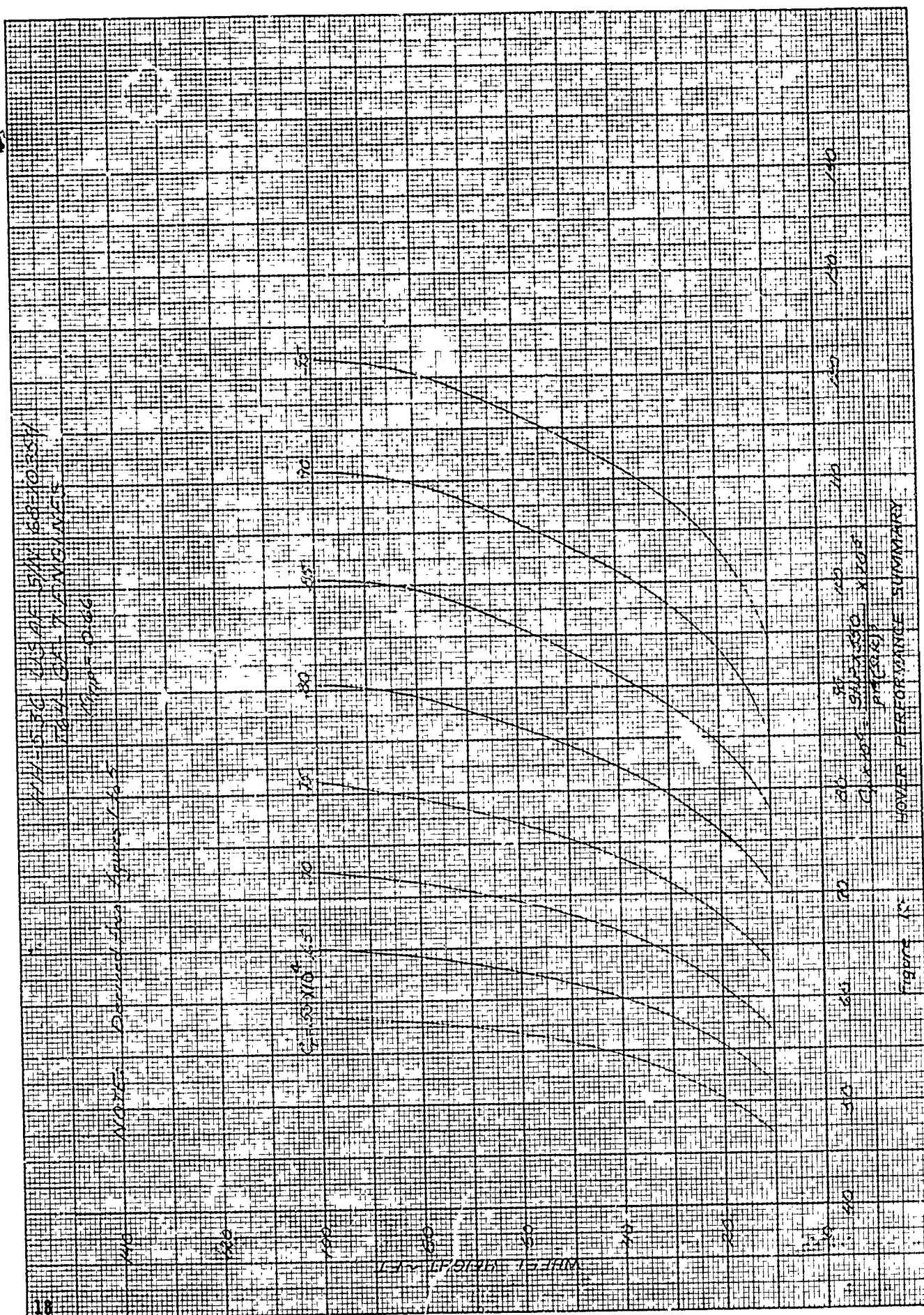




NOTE! Derivative of $\sin x = \cos x$



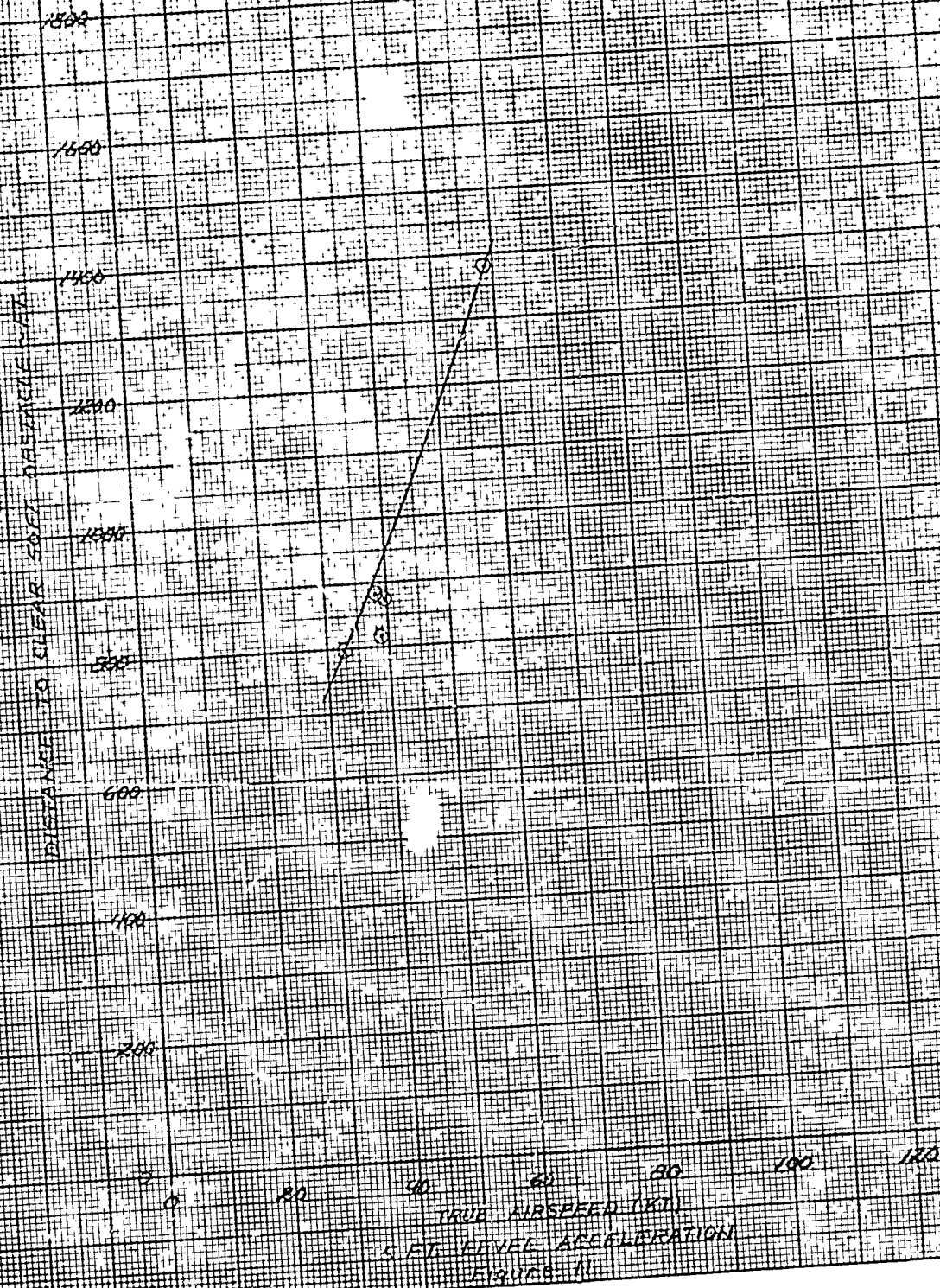
Figure 2



HH-53C USAF SIN 68-10354
T64-GE-7 ENGINES
 $ACF = 21 \times 10^{-5}$

NOTES:

ROTOR SPEED 194 RPM
LANDING GEAR DOWN



HH-53C USAF SIN 68-10354
T64-GE-7 ENGINES
 $AC_0 = 28 \times 10^{-6}$

NOTES:

ROTOR SPEED 196 RPM
LANDING GEAR DOWN

DISTANCE TO CLEAR 50 FT OBSTACLE - FT

1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0

0 20 40 60 80 100 120
TRUE AIRSPEED (KT)

5 FT LEVEL ACCELERATION

FIGURE 12

HH-53C USAF S/N 68-10354

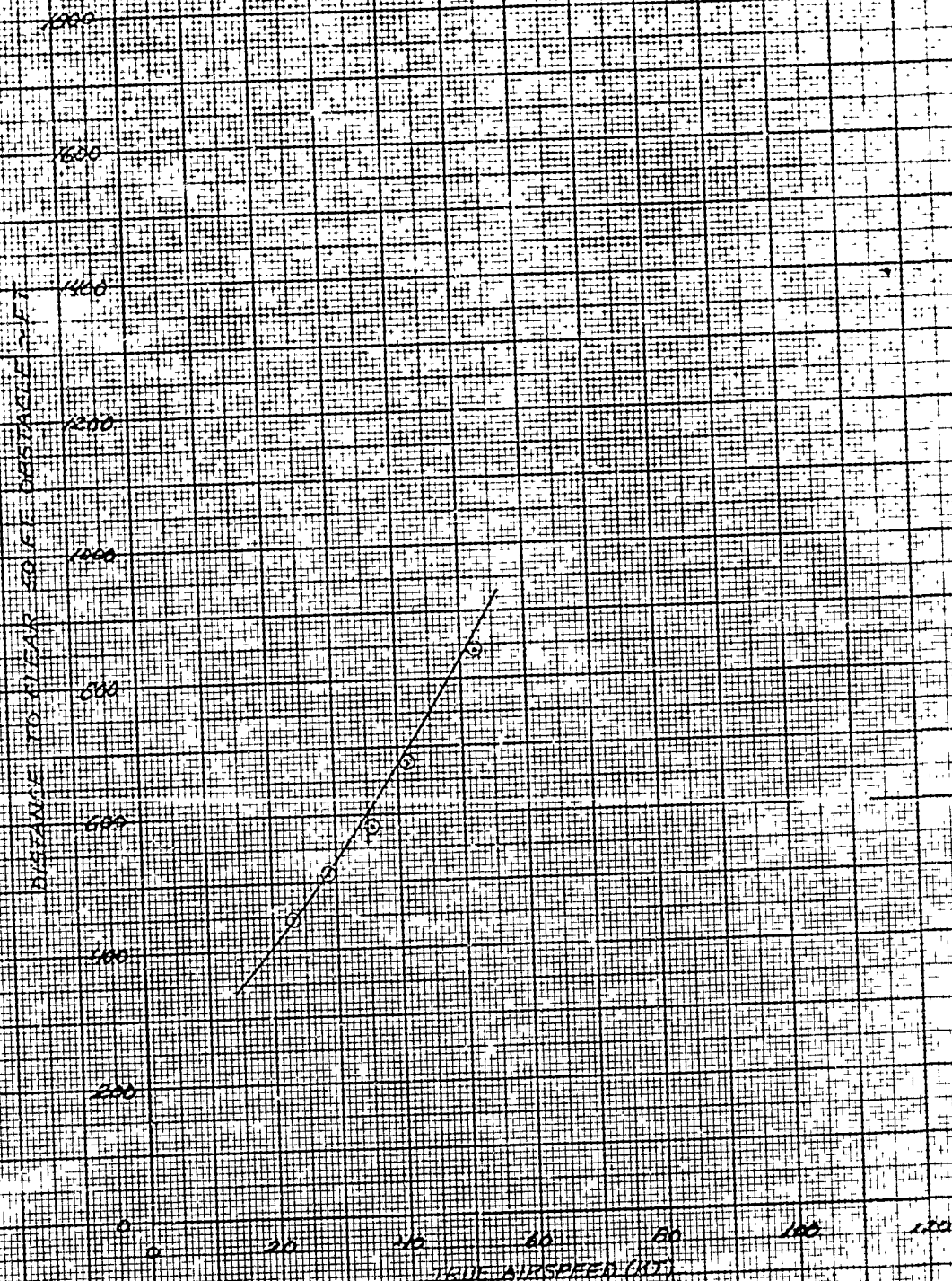
T62-GE-7 ENGINES

$ACD = 30.5 \times 10^{-6}$

NOTES:

ROTOR SPEED = 196 RPM

LANDING GEAR DOWN



5.1 - LEVEL ACCELERATION

Figure 13

HH-53C USAF SIN 68-10854

T64-GE-7 ENGINES

ACF = 33.8 X 10⁶

NOTES:

RYTOR SPEED = 196 RPM

LANDING GEAR DOWN

DISTANCE TO CLEAR 50 FT OBSTACLE (FT)

1500

1600

1400

1200

1000

800

600

400

200

0

0

20

40

60

80

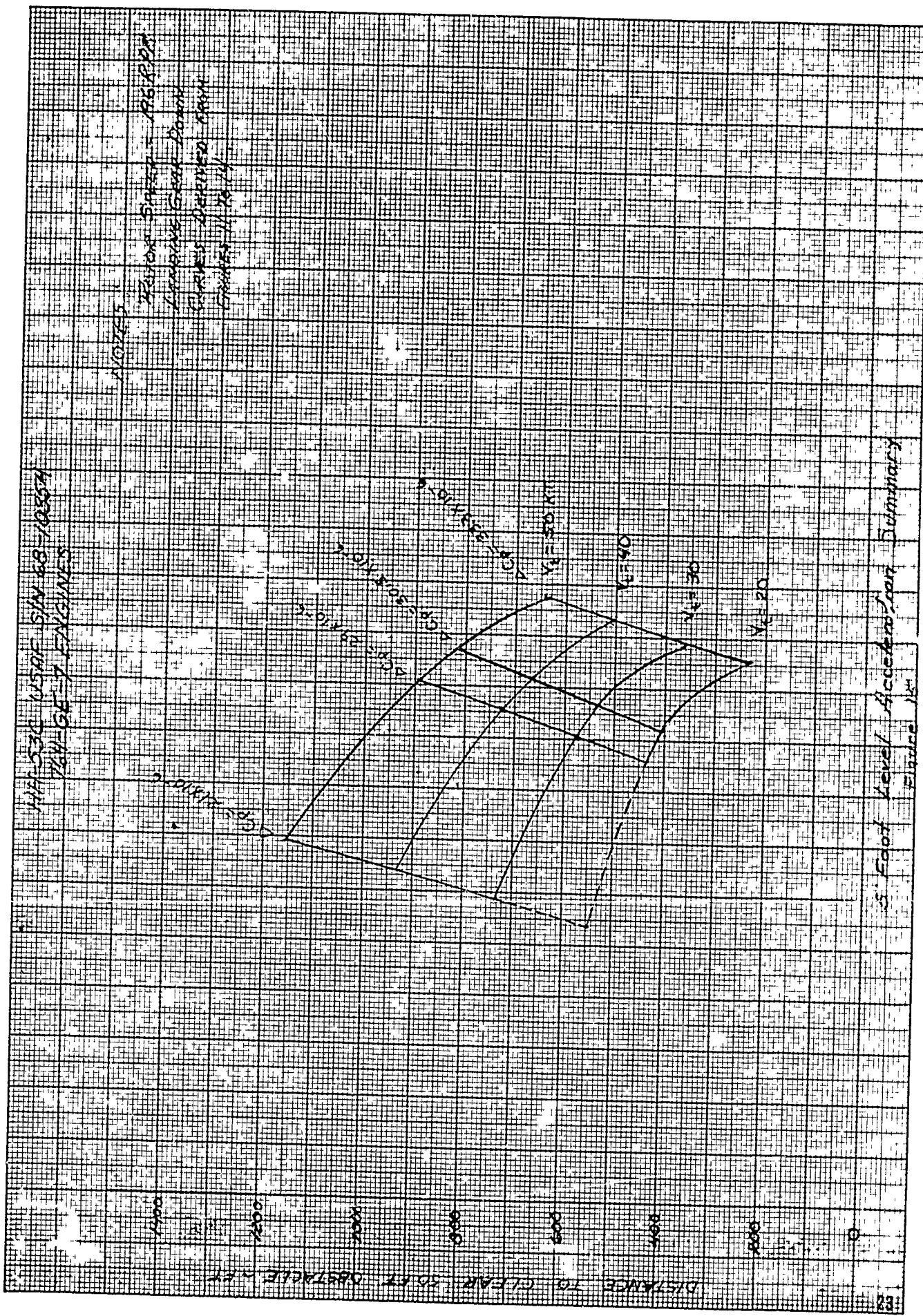
100

120

TRUE AIRSPEED (KT)

5 FT LEVEL ACCELERATION

Figure 14

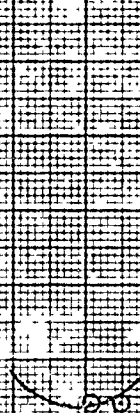


HH-53C USAF SIN 68-10354
 T64-GE-7 ENGINES
 ACP 9.6 X 10⁻⁶

NOTES

ROTOR SPEED: 198 RPM
 LANDING GEAR DOWN

DISTANCE TO CLEAR 50 FT OBSTACLE - FT



TRUE AIRSPEED (KT)
 15 KT LEVEL ACCELERATION

Figure 16

HH-53C USAF S/N 68-10354
T64-GE-7 ENGINES
ACF-1341/D-6

NOTES:

ROTOR SPEED: 190 RPM
LANDING GEAR DOWN

DISTANCE TO CLEAR 50 FT OBSTACLE - FT

1600
1400
1200
1000
800
600
400
200
0

0 20 40 60 80 100 120

TRUE AIRSPEED (KTS)

15 FT LEVEL ACCELERATION

Figure 17

HL-53C U.S.A.F. SIN 68-10354

T64-GE-7 ENGINES

$AC = 17.9 \times 10^6$

NOTES

ROTOR SPEED = 198 RPM

LANDING GEAR DOWN

DISTANCE TO CLEAR 50 FT OBSTACLE (FT)

1800

1600

1400

1200

1000

800

600

400

200

0

0

20

40

60

80

100

120

TRUE AIRSPEED (KT)

15 FT LEVEL ACCELERATION

FIGURE 18

HH-53C USAF SIN 68-10356

164-GB-7 ENGINES

ACF-23.3X10³

NOTES

ROTOR SPEED 196 RPM

LANDING GEAR DOWN

DISTANCE TO CLEAR 50-FT OBSTACLE (FEET)

1800

1600

1400

1200

1000

800

600

400

200

0

20

40

60

80

100

120

TRUE AIRSPEED (KTS)

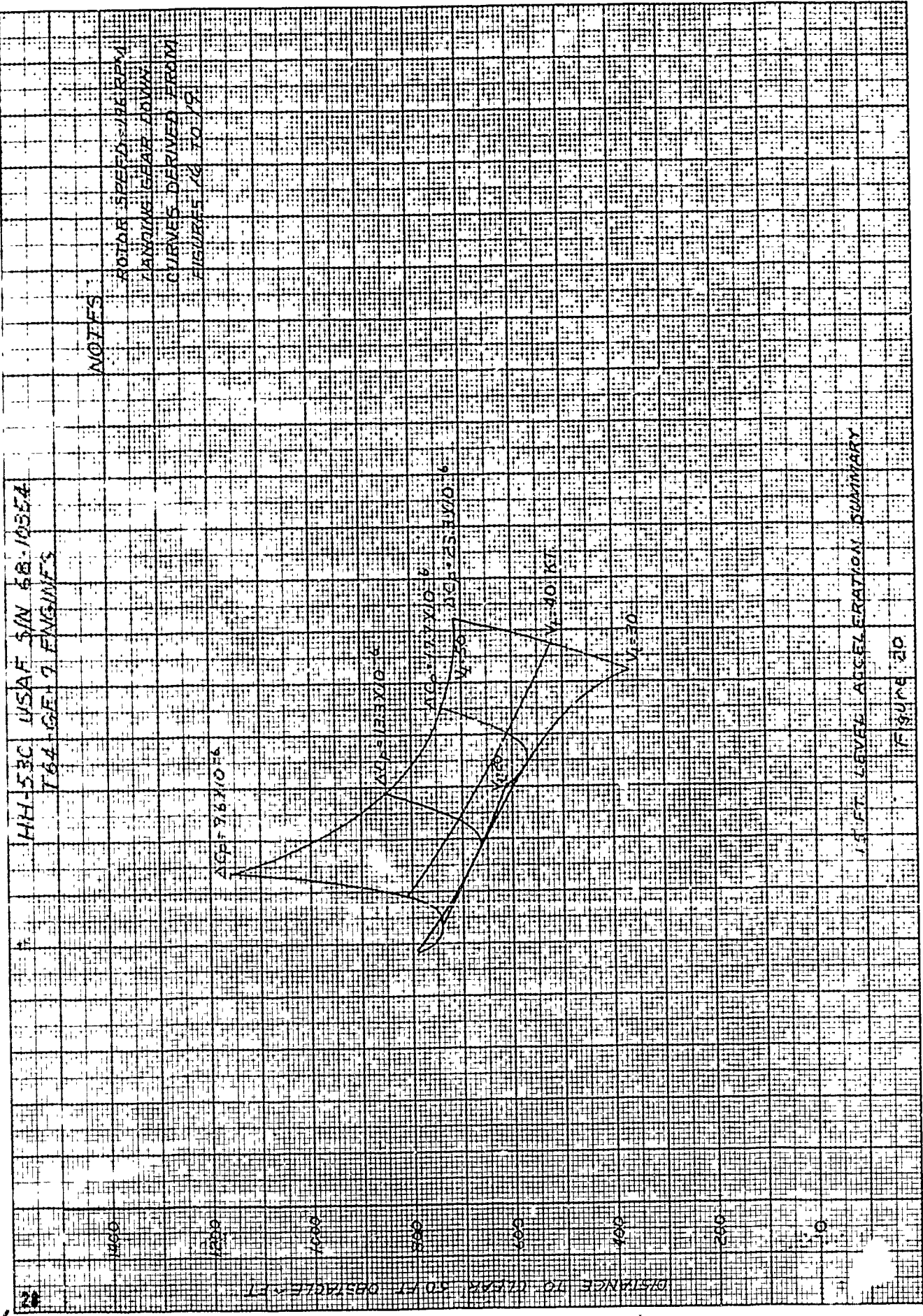
15 FT LEVEL ACCELERATION

Figure 15

HH-53C USAF S/N 68-10354
T64-GE-7 ENGINES

NOTES

ROTOR SPEED 300 RPM
LANDING GEAR DOWN
CURVES DERIVED FROM
FIGURES 10 TO 15



1.5 FT. LEVEL ACCELERATION SUMMARY
OF 300 RPM

HH-53G USAF S/N 68-10354

T64-G-7-ENGINE

Symbol	Avg. Cyl. Temp. (°F)	Avg. Press. (in)	Avg. Ambient Temp. (°C)	Avg. Cyl. Temp. (°F)	Rotor Speed (rpm)
(1)	41500	10000	10.5	340	186 (100%)
(2)	40500	10500	5.0	340	186 (100%)
(3)	41500	10000	14.0	340	186 (105%)

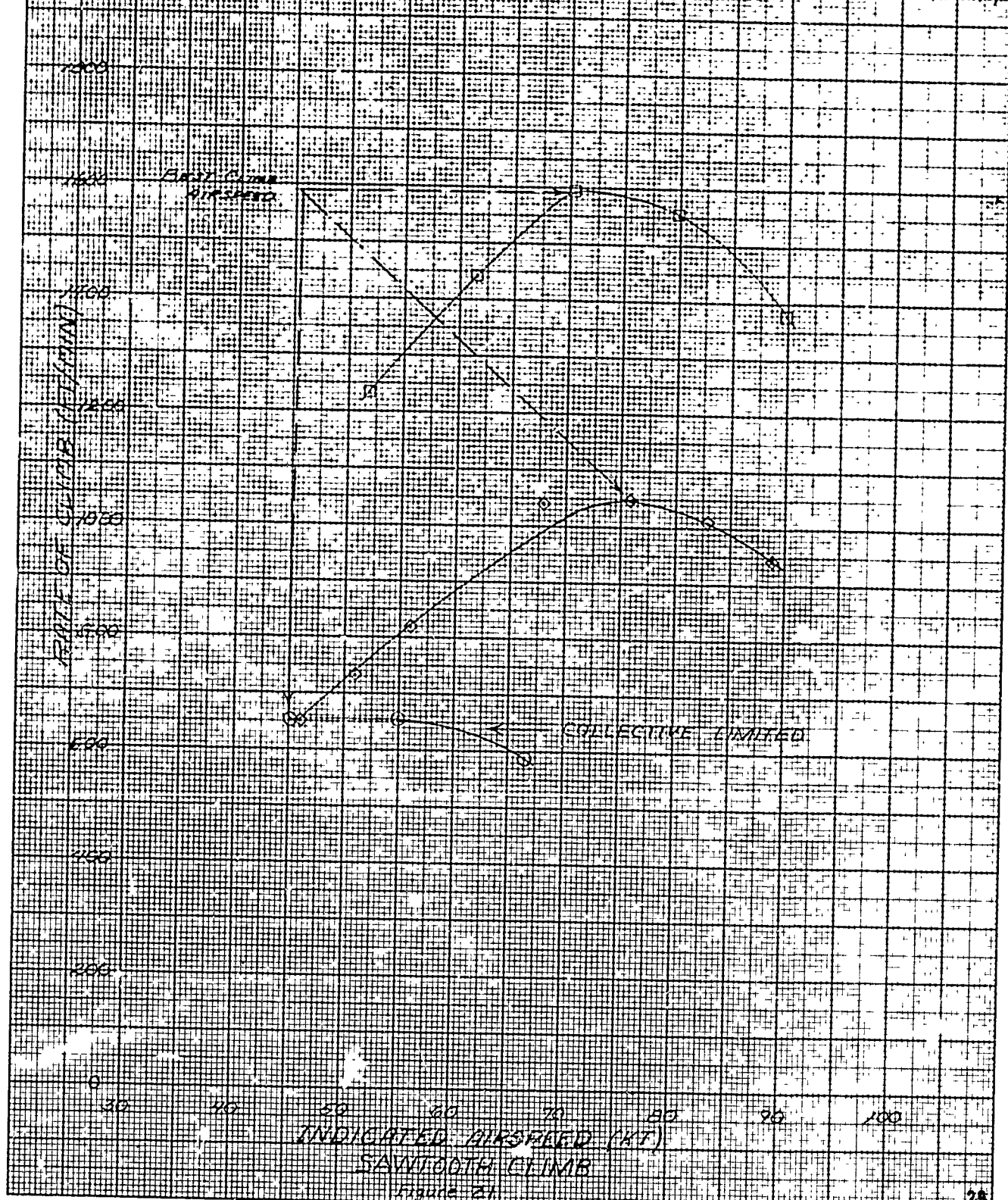


Figure 21

HH-53C USAF S/N 68-10354

T64 GE-7 ENGINES

APPROX 20-FOOT WHEEL HT

SIDEWARD FLIGHT

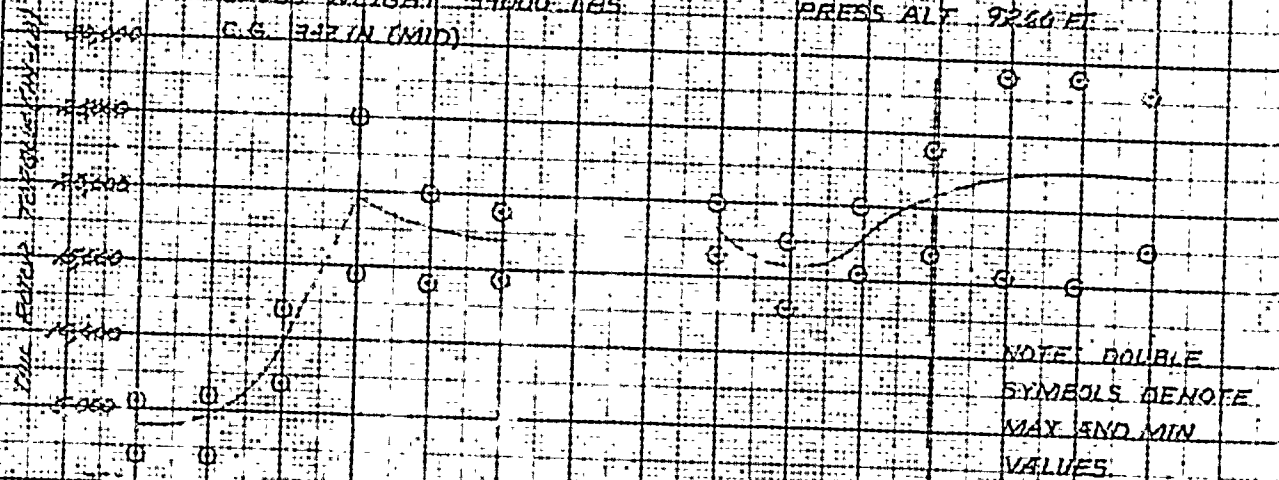
ROTOR SPEED 102%

GROSS WEIGHT 37000 LBS

C.G. 342 IN (MID)

AVG O.A.T. 46°C

PRESS ALT 9260 FT



NEW PERICRAV LIMIT

CONVENTIONAL LIMIT

TRANSLATIONAL LIFT

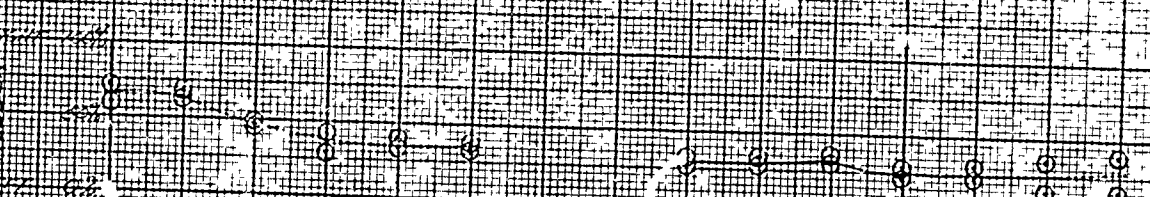
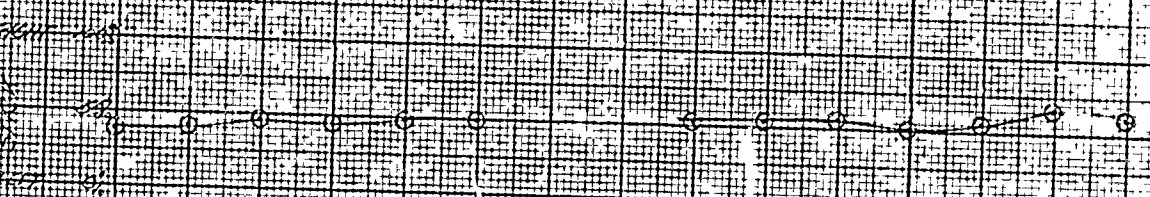
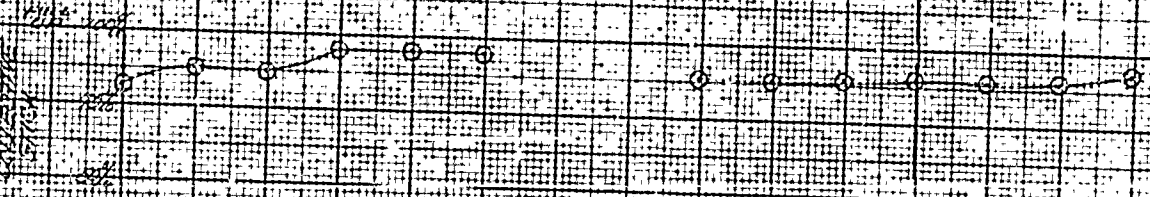
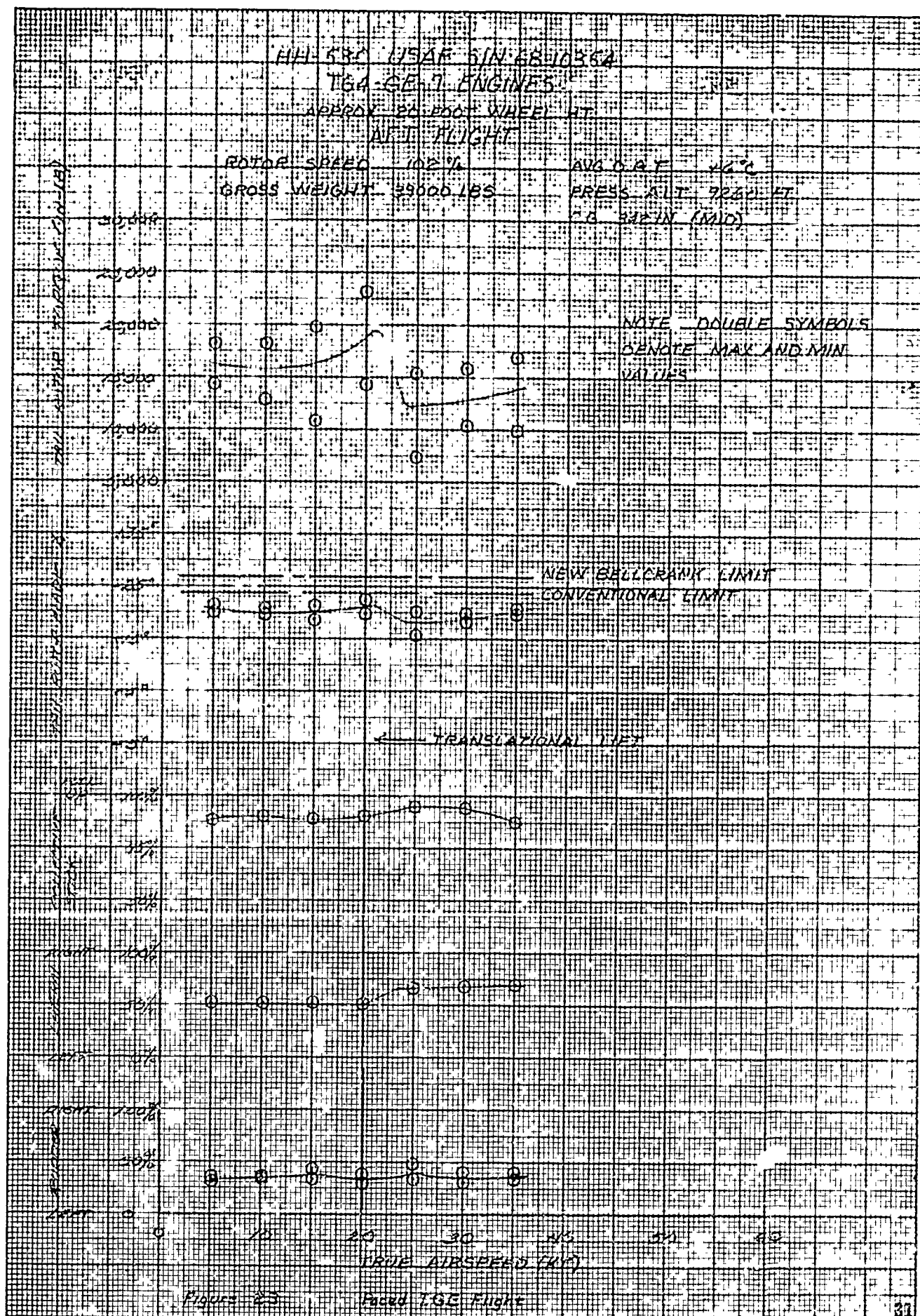


Figure 22

PERIOD OF FLIGHT



HH-53C USAF SIN 48-10354

T64-GE-7 ENGINES

APPROX 20 FOOT WHEEL HT

AFT QUARTERING FLIGHT

ROTOR SPEED 102%

AVG OATF 16°C

GROSS WEIGHT 29000 LBS

PRESS ALT 9260 FT

C.G. 742 IN (MID)

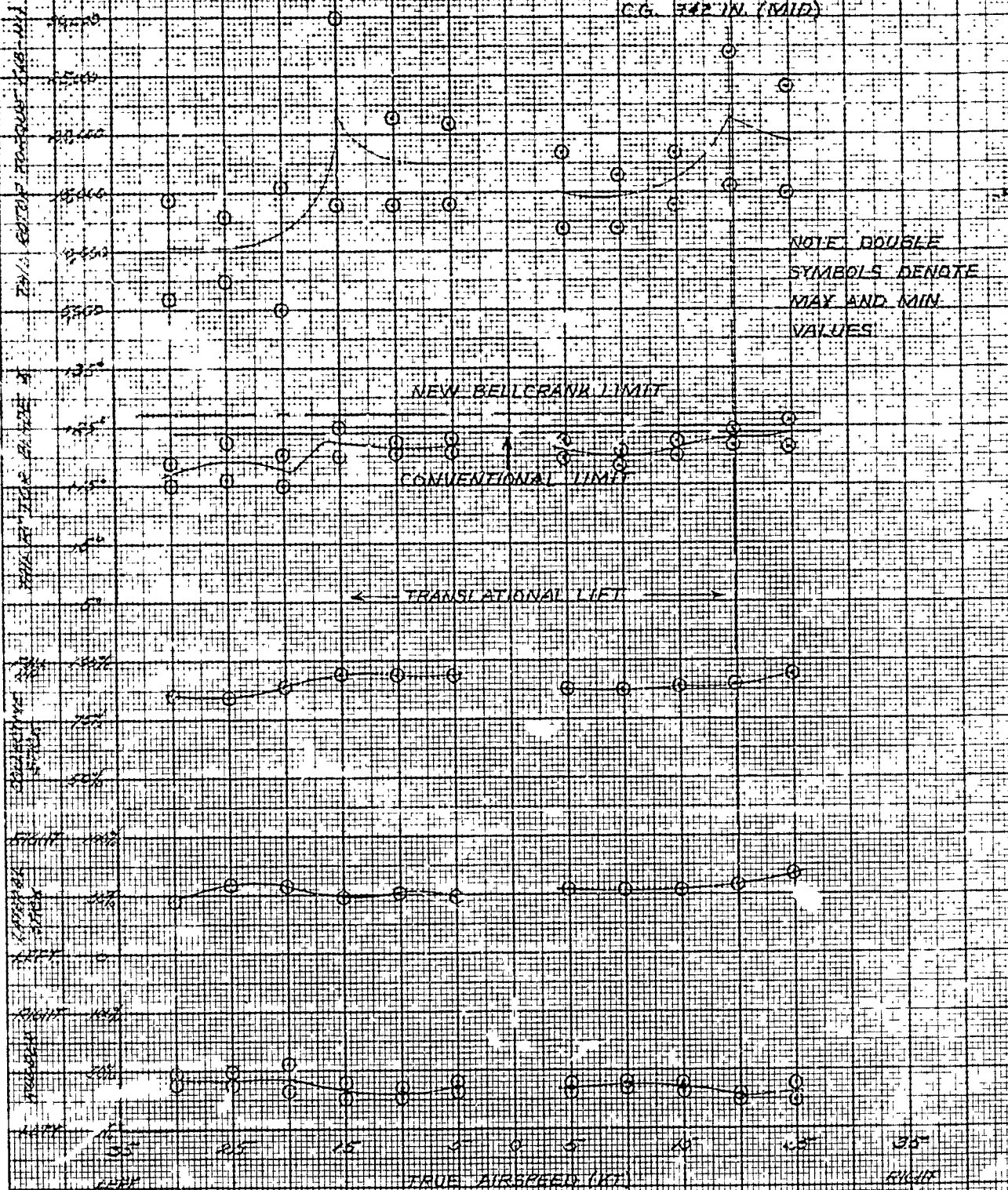


FIGURE 24

Fixed LIFT FLIGHT

HH-53C USAF SIN 68-10864

764 GE-7 ENGINES

APPROX 20 FOOT WHEEL WEIGHT

SIDEWARD FLIGHT

ROTOR SPEED 100%

AVE CAT 710T

GROSS WEIGHT 37,500 LBS

PRESS ALT 9400 FT

C.G. 328 IN (FWD)

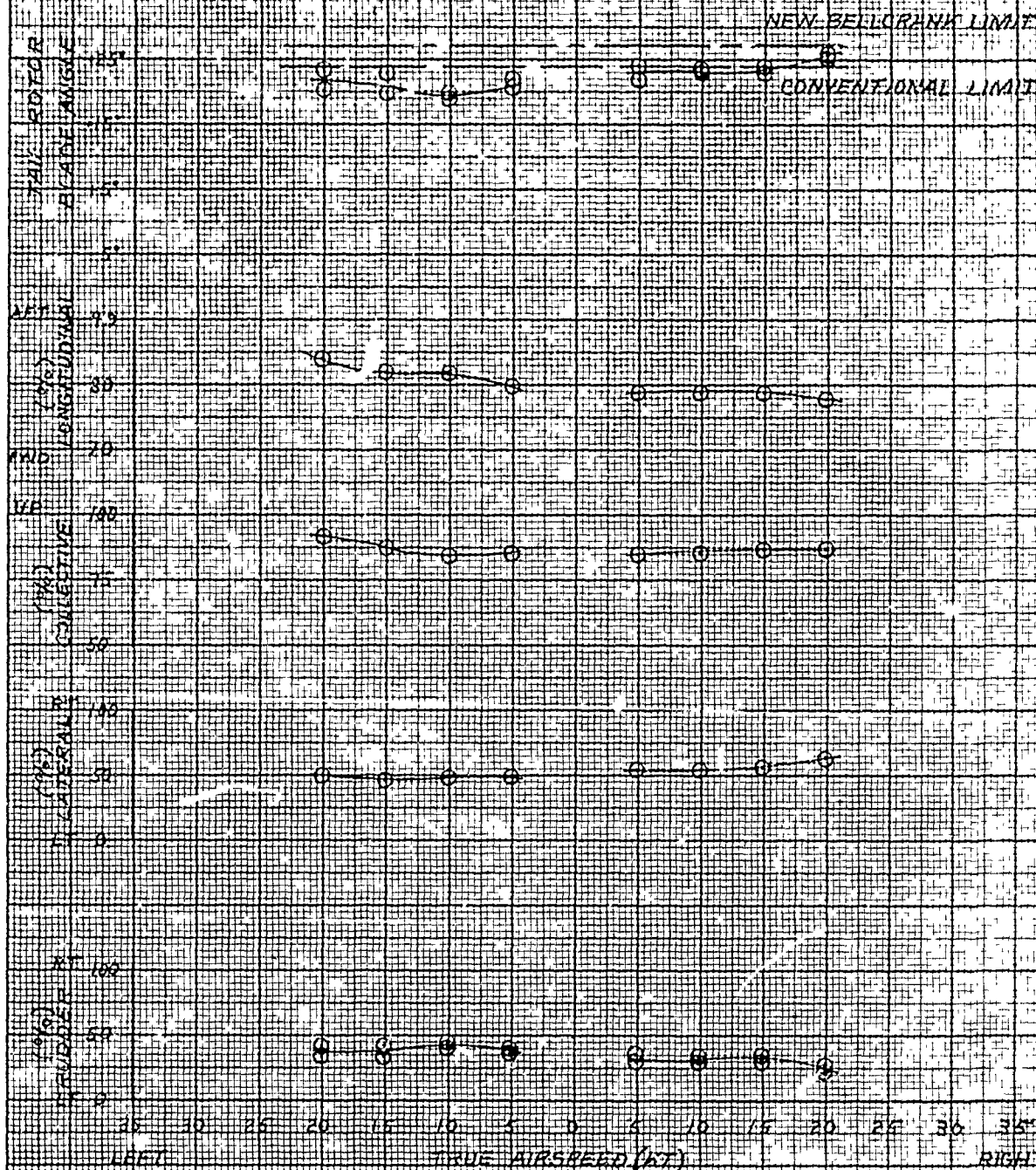


Figure E5

Paced LGE Flight

HH-53C USAF SN 68-10354

T64-GE-7 ENGINES

APPROX 20 FOOT WHEEL HEIGHT

AFT FLIGHT

ROTOR SPEED 100%

GROSS WEIGHT 37,500

AVG OAT 41°C

PRESS ALT 9400 FT

C.G. 828 IN. (FWD)



Figure 26

Paced IGE Flight

HH-53C USAF SINGR-10354

T64-GE-7 ENGINES

APPROX 20-FOOT WHEEL HEIGHT

AFT QUARTERING FLIGHT

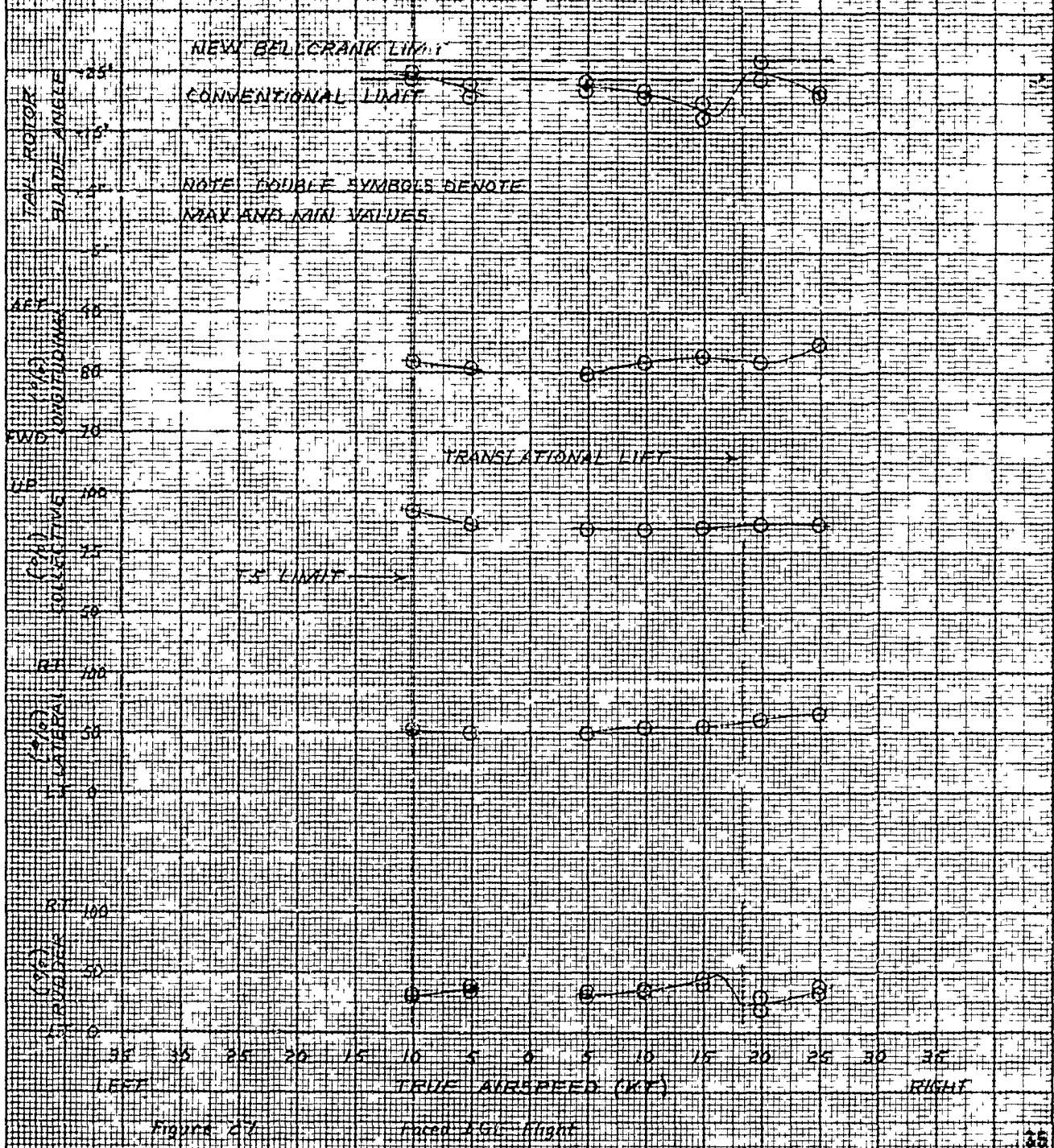
ROTOR SPEED 100%

AVG OAT 41.9°C

GROSS WEIGHT 37,500 LBS

PRESS ALT 9400 FT

CG 52.8 IN (FWD)



HH-53C USAF SIN 68-10354

T64-GE-7 ENGINES

APPROX 20 FT WHEEL HEIGHT

SIDEWARD FLIGHT

ROTOR SPEED 97%

AVG OAT 13.0

GROSS WEIGHT 37000 LBS

PRESS ALT 9480 FT

P.C. 532 IN (MID)

TAIL ROTOR TORQUE (IN-LB)

NOTE: DOUBLE SYMBOLS DENOTE
MAX AND MIN VALUES

BLADE

ANGLE

TAIL ROTOR

ANGLE

COLLECTIVE

STICK

RIGHT

LEFT

RIGHT

LEFT

RIGHT

LEFT

RIGHT

LEFT

RIGHT

LEFT

RIGHT

LEFT

RIGHT

LEFT

RIGHT

LEFT

RIGHT

LEFT

RIGHT

LEFT

RIGHT

LEFT

RIGHT

TRUE AIRSPEED (KT)

RIGHT

38

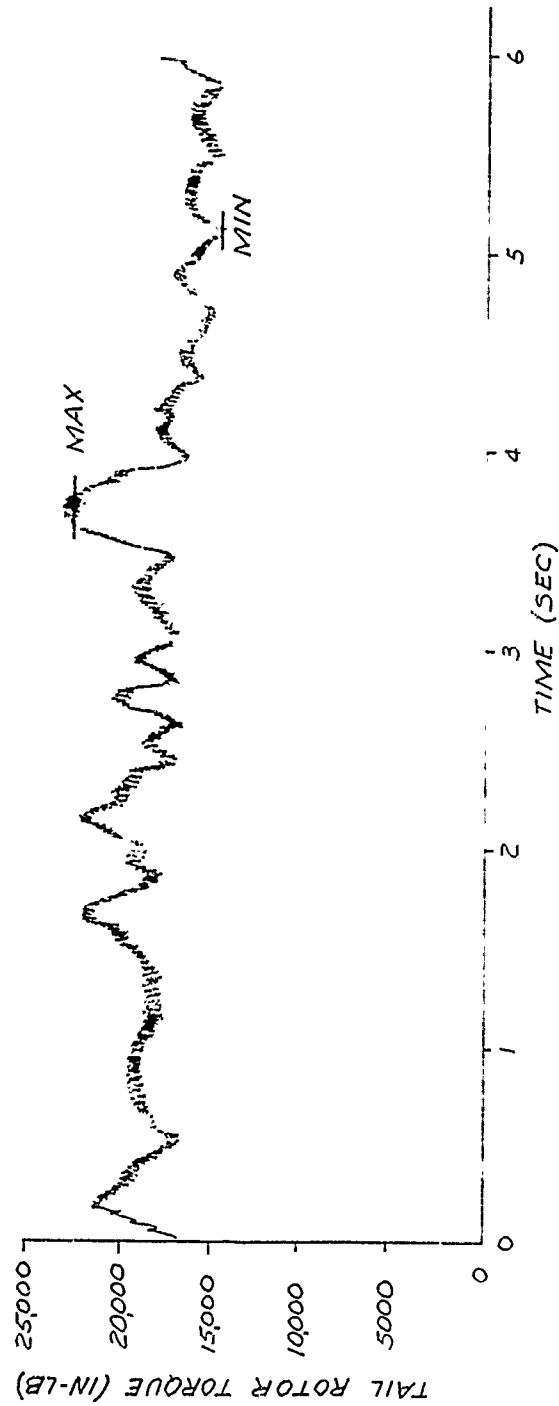
Figure 28

Forward Flight

HH-53C USAF SJA 68-10354
 T64-GE-7 ENGINES
 AFT FLIGHT

ROTOR SPEED 102 %
 GROSS WEIGHT 39000 LBS
 QAT +6 °C
 PRESS ALT 9260 FT
 C.G. 342 IN (MID)

NOTE: TYPICAL TIME HISTORY FOR
 TAIL ROTOR TORQUE SHOWING
 MAX AND MIN VALUES AS
 PRESENTED IN FIGURES
 22 THROUGH 28



TAIL ROTOR TORQUE TIME HISTORY

Figure 29

H4-53C USAF S/N 58-10354
 T84-GE-7 ENGINES
 10 FOOT WHEEL MEASUREMENT

SYMBOL ROTOR SPEED (RPM)
 190-195

190-195

SYMBOL

CONVENTIONAL LIMIT

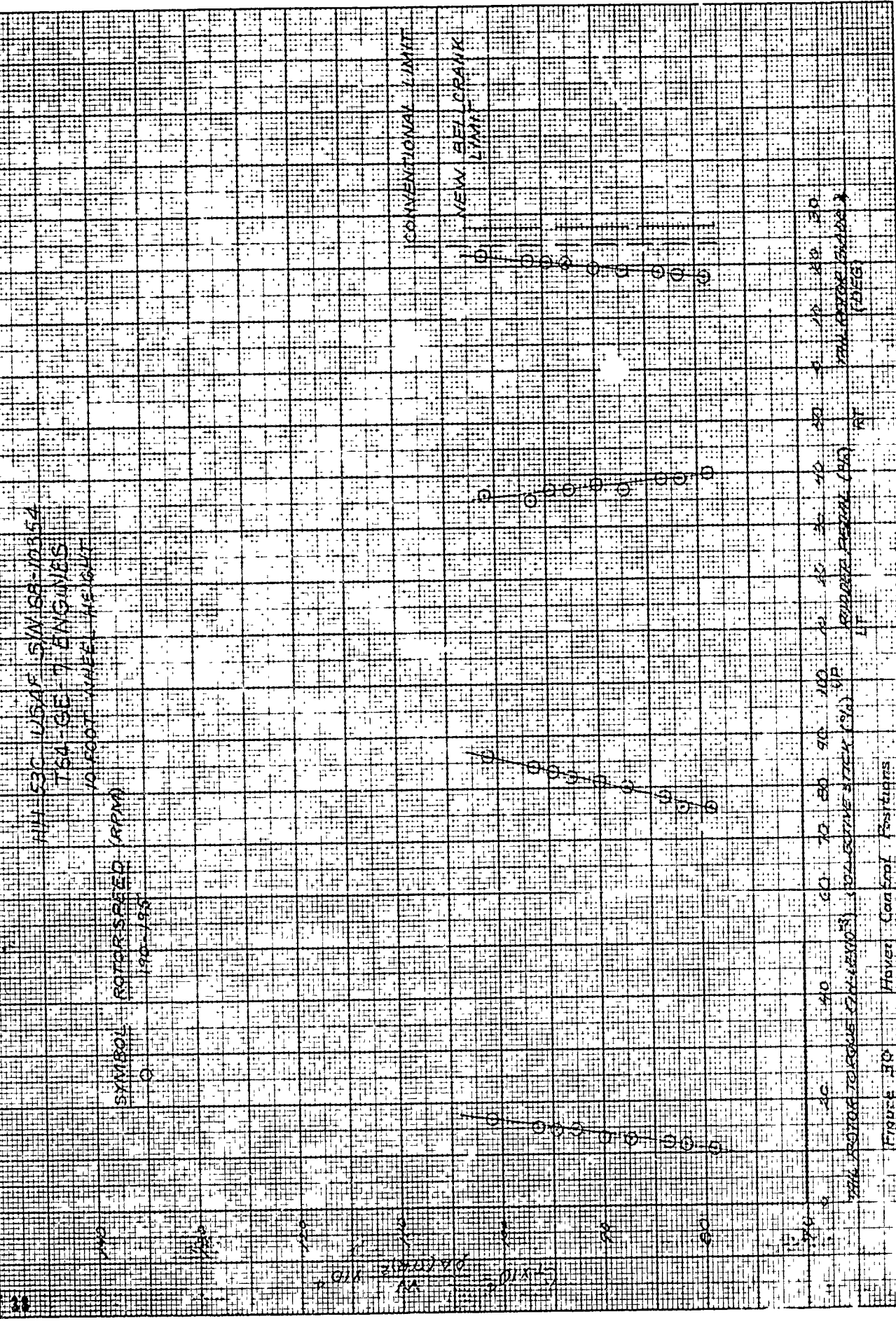
NEW BELL CRANK LIMIT

Hover Control Position
 Figure 30

WITH ROTOR TO FLOW (20-15000)
 COLLECTIVE STICK (100)

RUDDER PEDAL (100)
 RT

WITH ROTOR TO FLOW (20-15000)
 (UEEG)



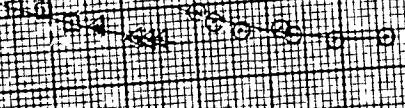
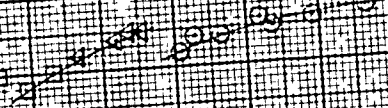
HILL-53C USAF SIN 68-10362
 T64 GE 7 ENGINES
 24-FOOT WHEEL HUBS

ROTOR SPEED (RPM)
 180-195
 180-185
 170-175

SYMBOL	ROTOR SPEED (RPM)
C	180-195
A	180-185
H	170-175

3 x 120000
 1 x 15

CONVENTIONAL LIGHT
 NEW BELLEFANT
 LIGHT



TAIL ROTOR BLADES
 (FUEL)
 AT
 35 40 45 50 55 60 65 70 75 80 85 90 95 100

TAIL ROTOR BLADES
 (FUEL)
 AT
 35 40 45 50 55 60 65 70 75 80 85 90 95 100

TAIL ROTOR BLADES
 (FUEL)
 AT
 35 40 45 50 55 60 65 70 75 80 85 90 95 100

HH-53C USAF S/N 63-10354

T76A+GE	7 ENGINES
---------	-----------

505 T. W. WILSON

SYMBOL ROTOR SET: ED, (RPN)

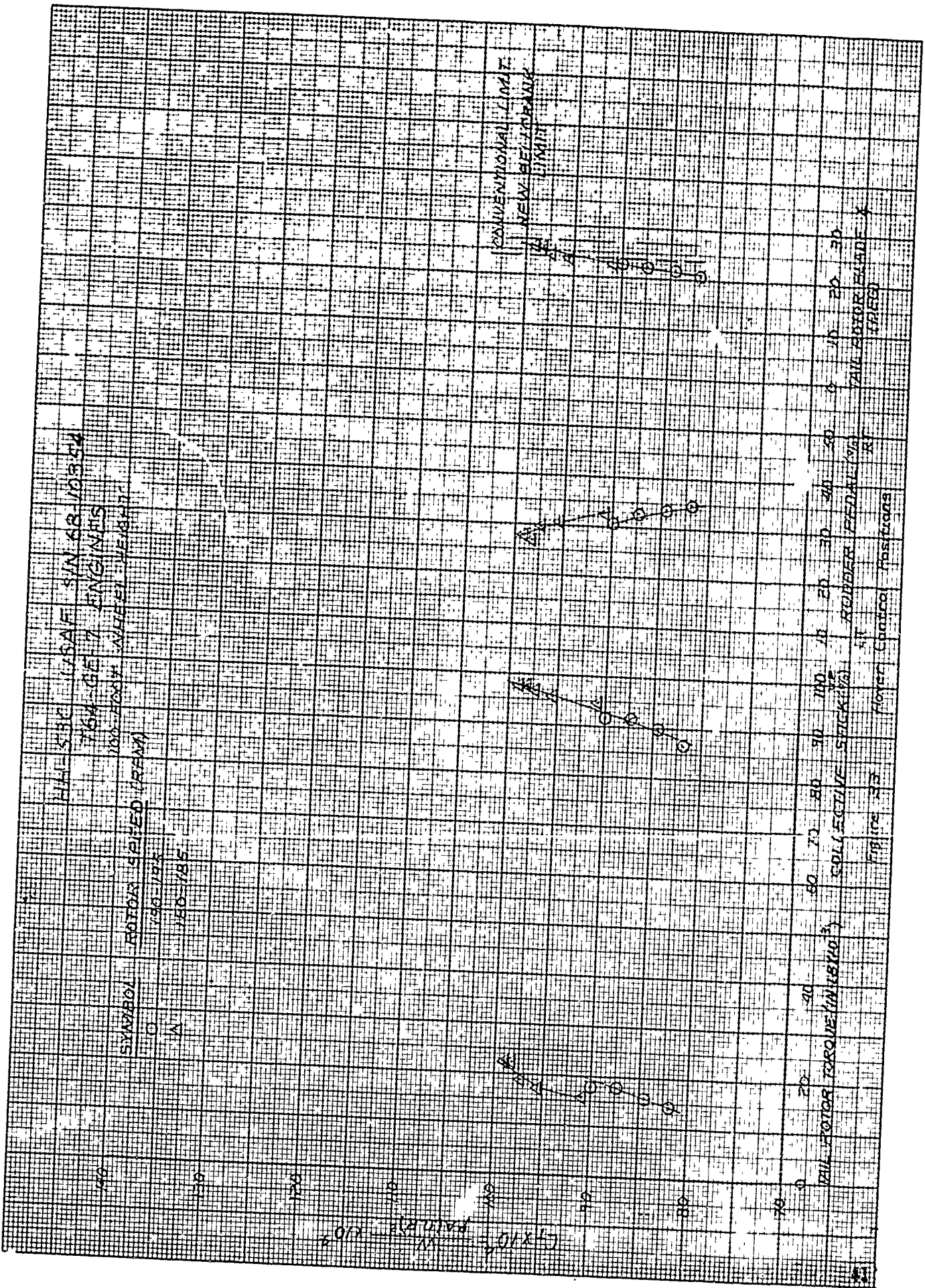
5.6470614

七

HOW POWER FORGIVE ME YES? CALL ECTIVE STRIKE UP
 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100 101 102 103 104 105 106 107 108 109 110 111 112 113 114 115 116 117 118 119 120 121 122 123 124 125 126 127 128 129 130 131 132 133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152 153 154 155 156 157 158 159 160 161 162 163 164 165 166 167 168 169 170 171 172 173 174 175 176 177 178 179 180 181 182 183 184 185 186 187 188 189 190 191 192 193 194 195 196 197 198 199 200 201 202 203 204 205 206 207 208 209 210 211 212 213 214 215 216 217 218 219 220 221 222 223 224 225 226 227 228 229 230 231 232 233 234 235 236 237 238 239 240 241 242 243 244 245 246 247 248 249 250 251 252 253 254 255 256 257 258 259 260 261 262 263 264 265 266 267 268 269 270 271 272 273 274 275 276 277 278 279 280 281 282 283 284 285 286 287 288 289 290 291 292 293 294 295 296 297 298 299 300 301 302 303 304 305 306 307 308 309 310 311 312 313 314 315 316 317 318 319 320 321 322 323 324 325 326 327 328 329 330 331 332 333 334 335 336 337 338 339 340 341 342 343 344 345 346 347 348 349 350 351 352 353 354 355 356 357 358 359 360 361 362 363 364 365 366 367 368 369 370 371 372 373 374 375 376 377 378 379 380 381 382 383 384 385 386 387 388 389 390 391 392 393 394 395 396 397 398 399 400 401 402 403 404 405 406 407 408 409 410 411 412 413 414 415 416 417 418 419 420 421 422 423 424 425 426 427 428 429 430 431 432 433 434 435 436 437 438 439 440 441 442 443 444 445 446 447 448 449 450 451 452 453 454 455 456 457 458 459 460 461 462 463 464 465 466 467 468 469 470 471 472 473 474 475 476 477 478 479 480 481 482 483 484 485 486 487 488 489 490 491 492 493 494 495 496 497 498 499 500 501 502 503 504 505 506 507 508 509 510 511 512 513 514 515 516 517 518 519 520 521 522 523 524 525 526 527 528 529 530 531 532 533 534 535 536 537 538 539 540 541 542 543 544 545 546 547 548 549 550 551 552 553 554 555 556 557 558 559 560 561 562 563 564 565 566 567 568 569 570 571 572 573 574 575 576 577 578 579 580 581 582 583 584 585 586 587 588 589 590 591 592 593 594 595 596 597 598 599 600 601 602 603 604 605 606 607 608 609 610 611 612 613 614 615 616 617 618 619 620 621 622 623 624 625 626 627 628 629 630 631 632 633 634 635 636 637 638 639 640 641 642 643 644 645 646 647 648 649 650 651 652 653 654 655 656 657 658 659 660 661 662 663 664 665 666 667 668 669 670 671 672 673 674 675 676 677 678 679 680 681 682 683 684 685 686 687 688 689 690 691 692 693 694 695 696 697 698 699 700 701 702 703 704 705 706 707 708 709 710 711 712 713 714 715 716 717 718 719 720 721 722 723 724 725 726 727 728 729 730 731 732 733 734 735 736 737 738 739 740 741 742 743 744 745 746 747 748 749 750 751 752 753 754 755 756 757 758 759 760 761 762 763 764 765 766 767 768 769 770 771 772 773 774 775 776 777 778 779 780 781 782 783 784 785 786 787 788 789 790 791 792 793 794 795 796 797 798 799 800 801 802 803 804 805 806 807 808 809 810 811 812 813 814 815 816 817 818 819 820 821 822 823 824 825 826 827 828 829 830 831 832 833 834 835 836 837 838 839 840 841 842 843 844 845 846 847 848 849 850 851 852 853 854 855 856 857 858 859 860 861 862 863 864 865 866 867 868 869 870 871 872 873 874 875 876 877 878 879 880 881 882 883 884 885 886 887 888 889 890 891 892 893 894 895 896 897 898 899 900 901 902 903 904 905 906 907 908 909 910 911 912 913 914 915 916 917 918 919 920 921 922 923 924 925 926 927 928 929 930 931 932 933 934 935 936 937 938 939 940 941 942 943 944 945 946 947 948 949 950 951 952 953 954 955 956 957 958 959 960 961 962 963 964 965 966 967 968 969 970 971 972 973 974 975 976 977 978 979 980 981 982 983 984 985 986 987 988 989 990 991 992 993 994 995 996 997 998 999 1000 1001 1002 1003 1004 1005 1006 1007 1008 1009 1010 1011 1012 1013 1014 1015 1016 1017 1018 1019 1020 1021 1022 1023 1024 1025 1026 1027 1028 1029 1030 1031 1032 1033 1034 1035 1036 1

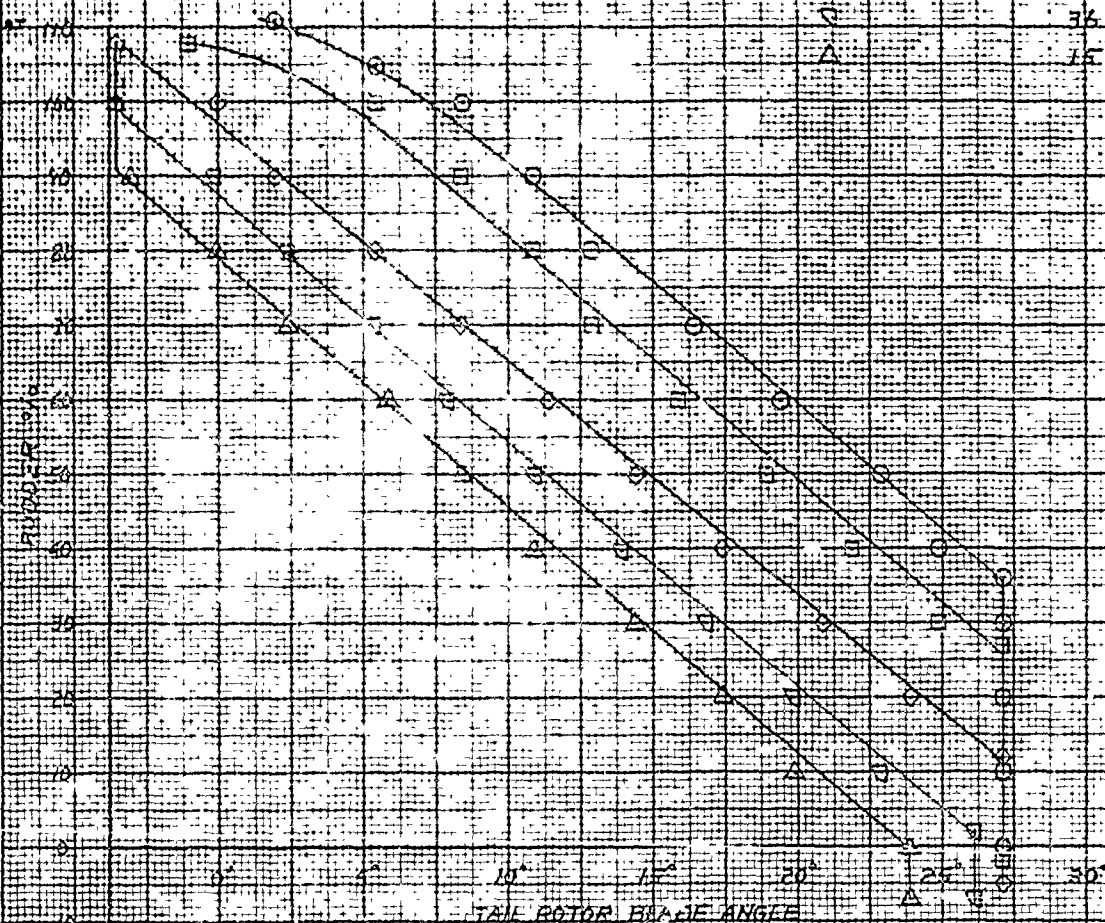
Hoyer Control Systems

1997-98



HH-53E USAF S/N 68-10354
T64-GE-7 ENGINES

SYMBOL	COLLECTIVE POSITION
○	100%
□	77 1/2%
◇	55 1/2%
△	33 1/2%
▽	11 1/2%

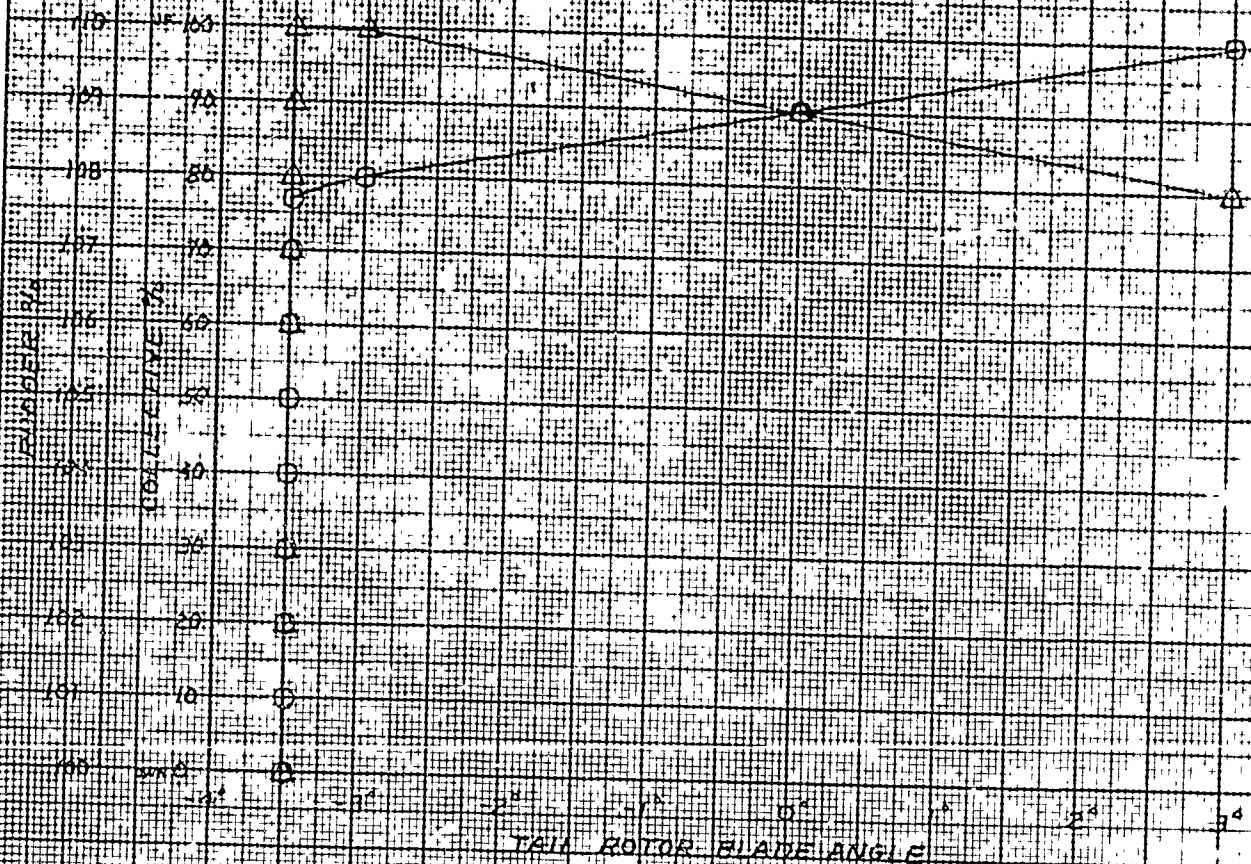


COLLECTIVE-RUDDER COUPLING

Figure 34

FH-93C USAF SIN 48-10354
T64-GE-7 ENGINES

APSC ON
O COLLECTIVE
100% RUDDER NORMAL FULL RIGHT
100% RUDDER MAX FULL RIGHT
Δ RUDDER

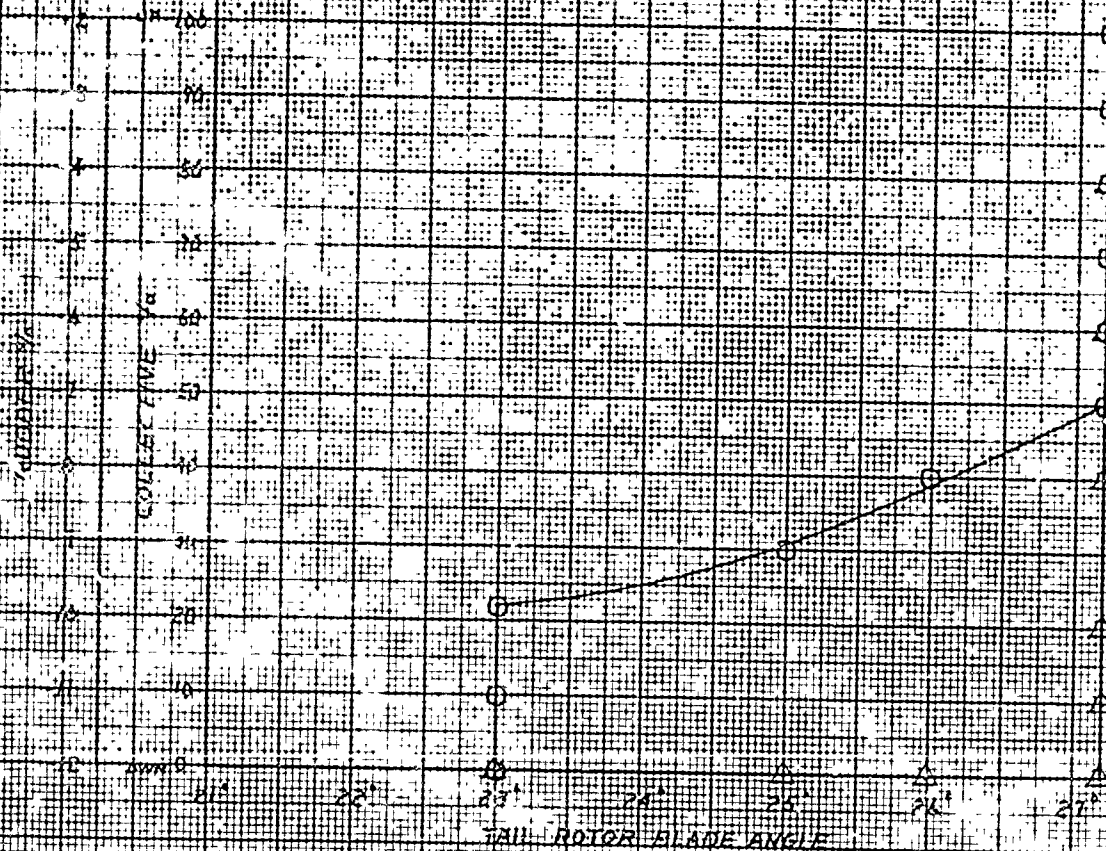


COLLECTIVE RUDDER COUPLING

Figure 35

AH-56C (15A) SN 18-10352
 T64-GE-1 ENGINES

AFSC ON
 ○ COLLECTIVE
 △ RUDDER
 0% RUDDER NORMAL FULL LEET
 -12% RUDDER MAX FULL LEET



COLLECTIVE RUDDER COUPLING

Figure 36

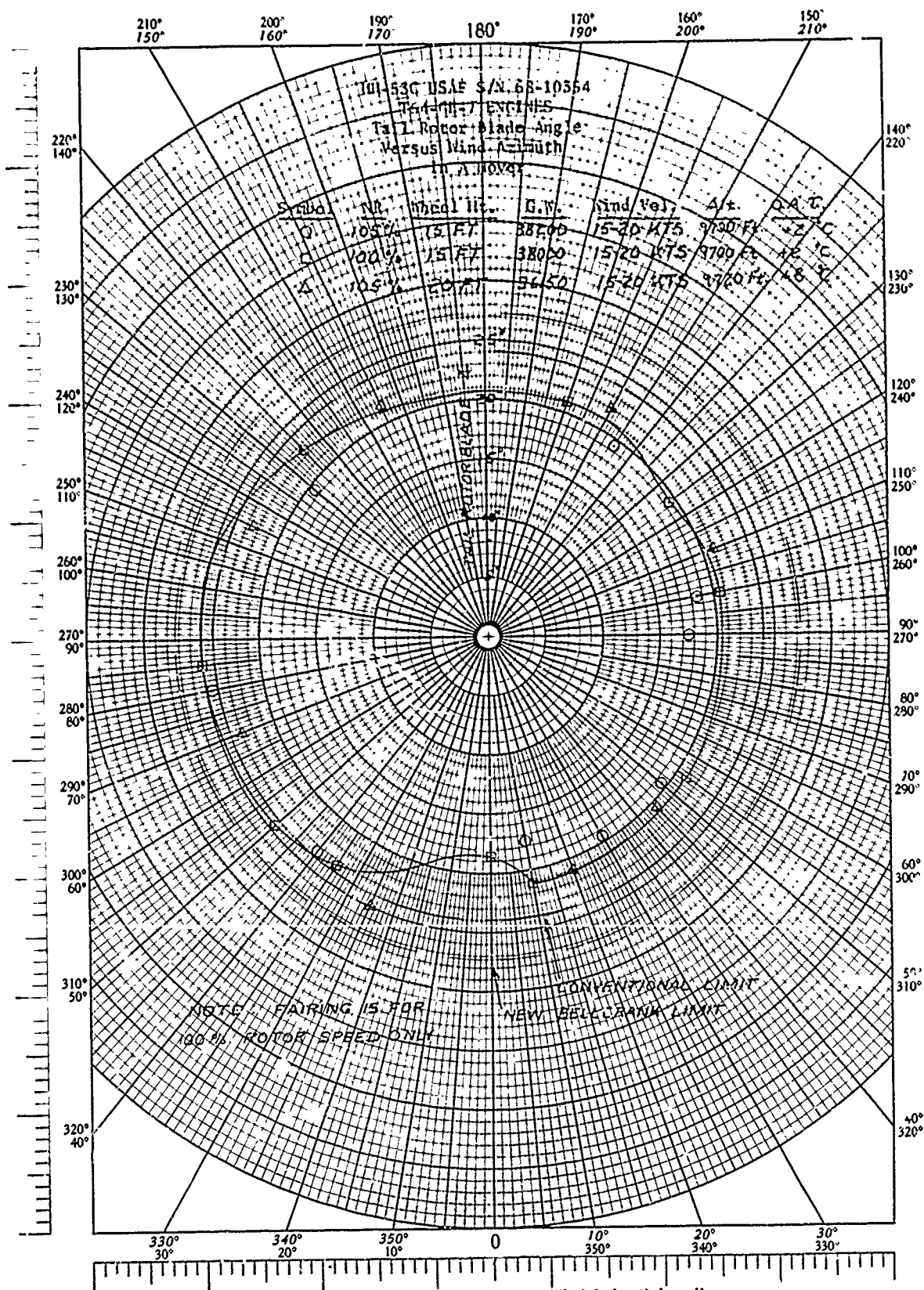


Figure 37 Tail Rotor Blade Angle versus Wind Azimuth in a Hover

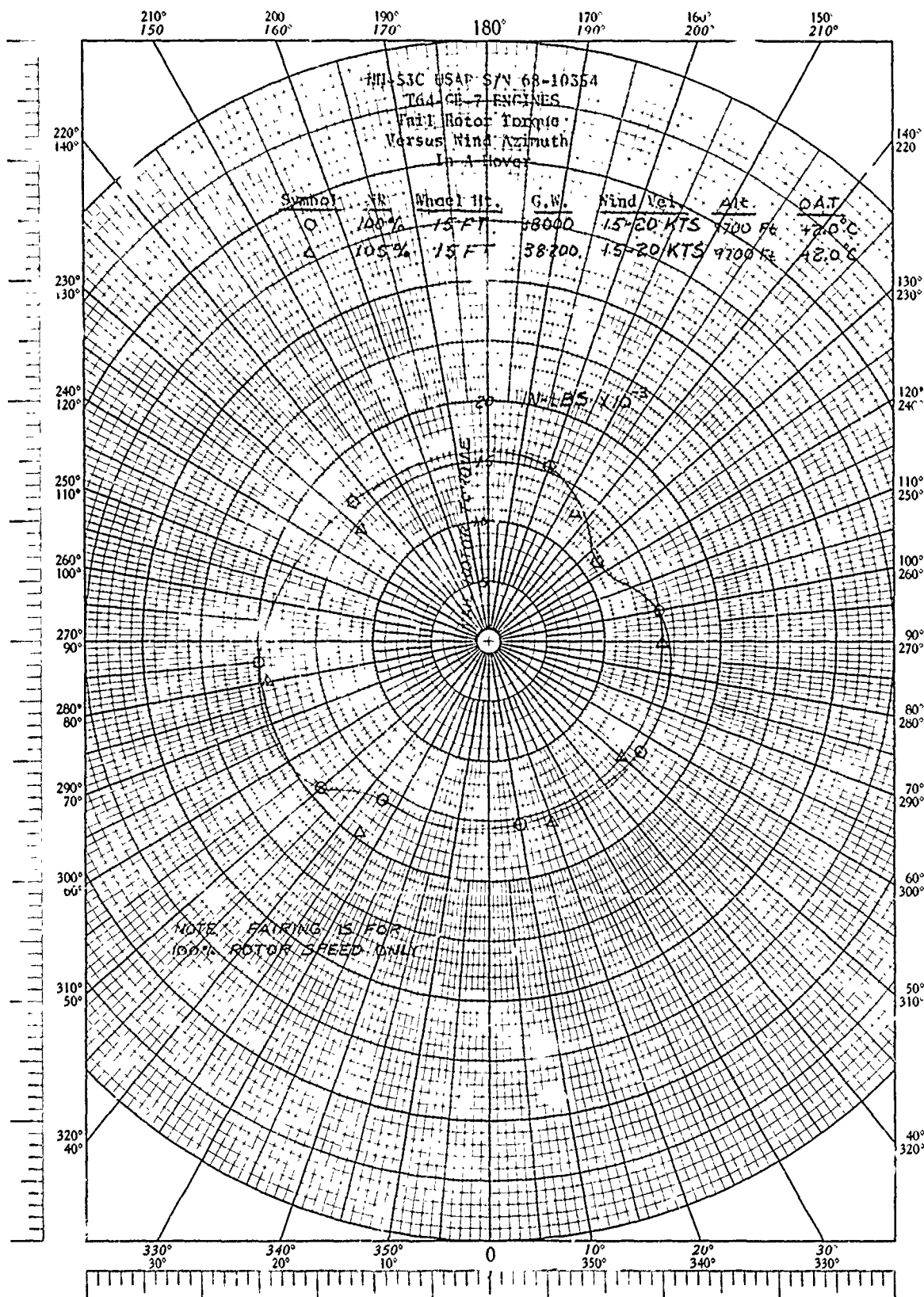


Figure 38 Tail Rotor Torque versus Wind Azimuth in a Hover

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2. Flight Manual USAF Series HH-53B, HH-53C Helicopter, T.O. 1H-53(H) B-1, 30 June 1970, changed 30 June 1971.
3. Gurley, Sydney E., Major USAF; Lovrien, Clark E., Jr., Major USAF; Ritter, Rodney L., Captain USAF, Cold Weather Hover Performance, (Supplement), FTC-TR-70-8, Air Force Flight Test Center, April 1971.
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<p>This limited flight test program defined the hover and takeoff performance of the HH-53C helicopter at high altitude and included an evaluation of the increased tail rotor power provided by a new tail rotor bellcrank. Hover and takeoff performance were satisfactory during high altitude testing. Operating at 105-percent rotor speed at high altitude, heavy gross weight combinations provided a more rapid response of the aircraft to control inputs than operation at 100-percent where control response was somewhat sluggish. In addition, it provided increased performance, prevented reaching mechanical control stops from limiting performance and lowered cruise guide readings. The new tail rotor bellcrank increased the HH-53C lift capability approximately 4,500 pounds by preventing tail rotor authority from limiting aircraft performance. A compromise between maximum performance and safety resulted in recommendation of a 35 knot indicated airspeed for takeoff.</p>		

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1 NOV 65

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14

KEY WORDS

LINK A

LINK B

LINK C

ROLE

WT

ROLE

WT

ROLE

WT

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performance
high altitude performance
takeoff
hover
tail rotor
control response
lift capability